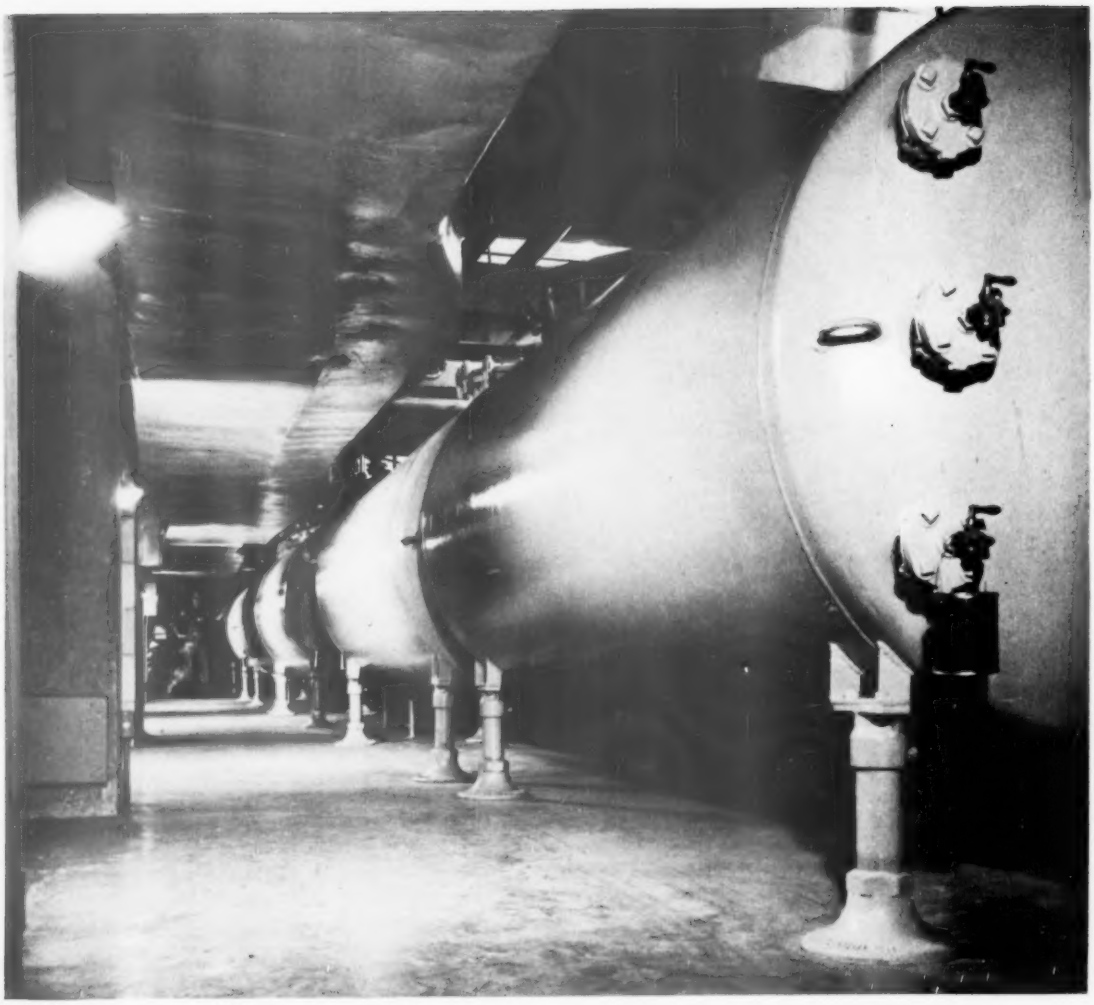
NUCLEONICS

April 1953



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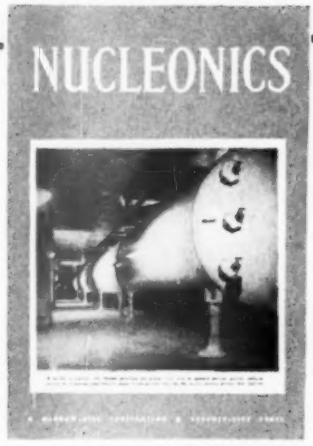

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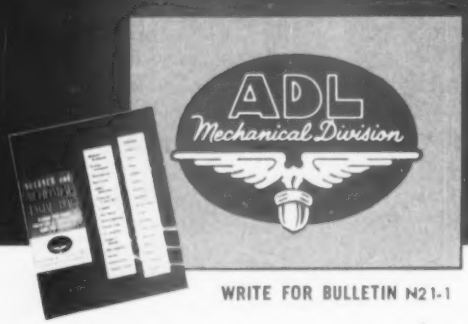

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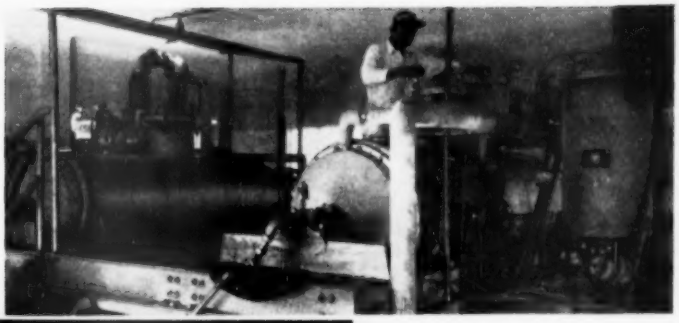

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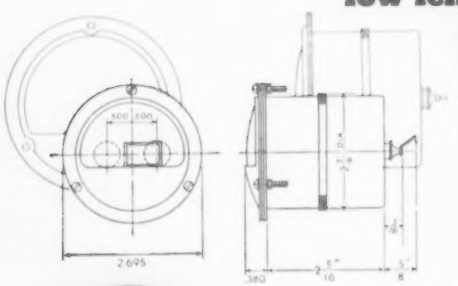

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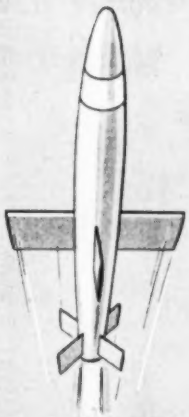

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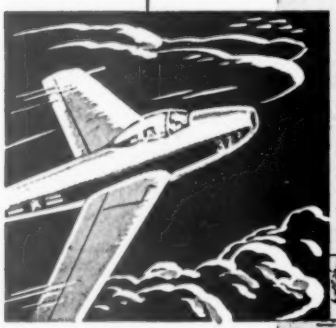

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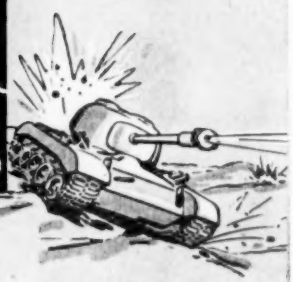
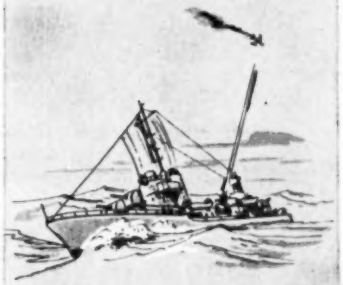


Stabilizing the guns on bouncing tanks



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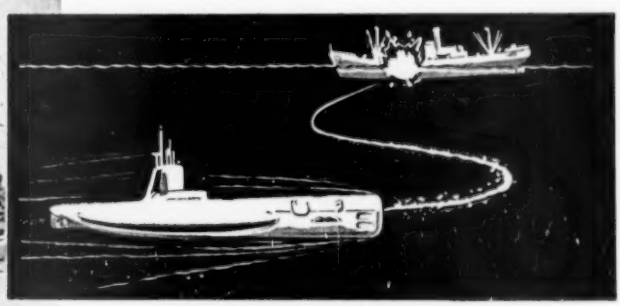

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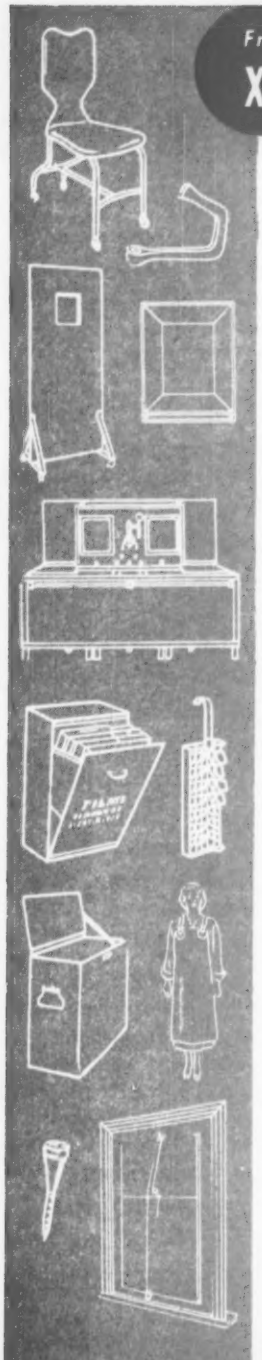

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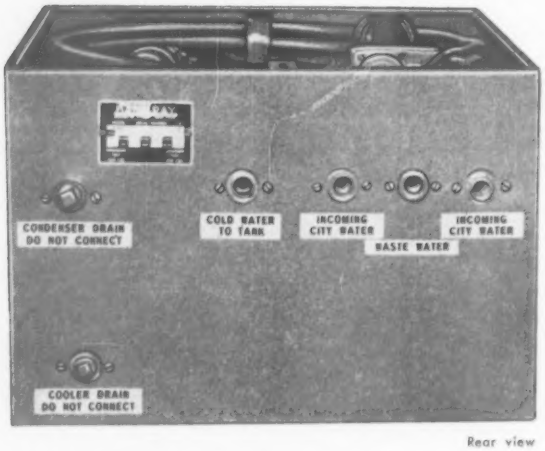

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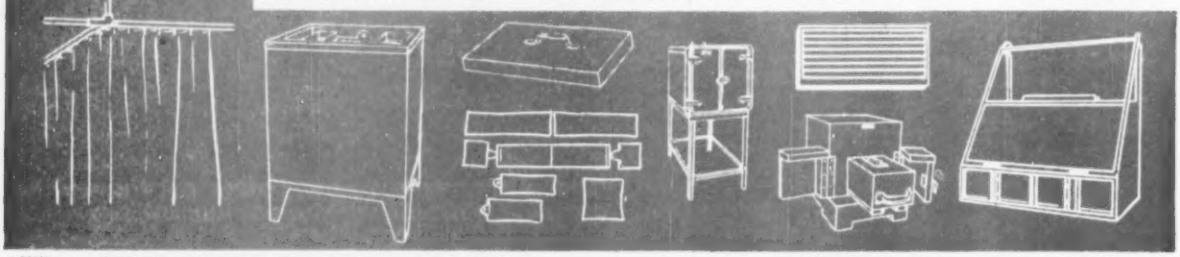

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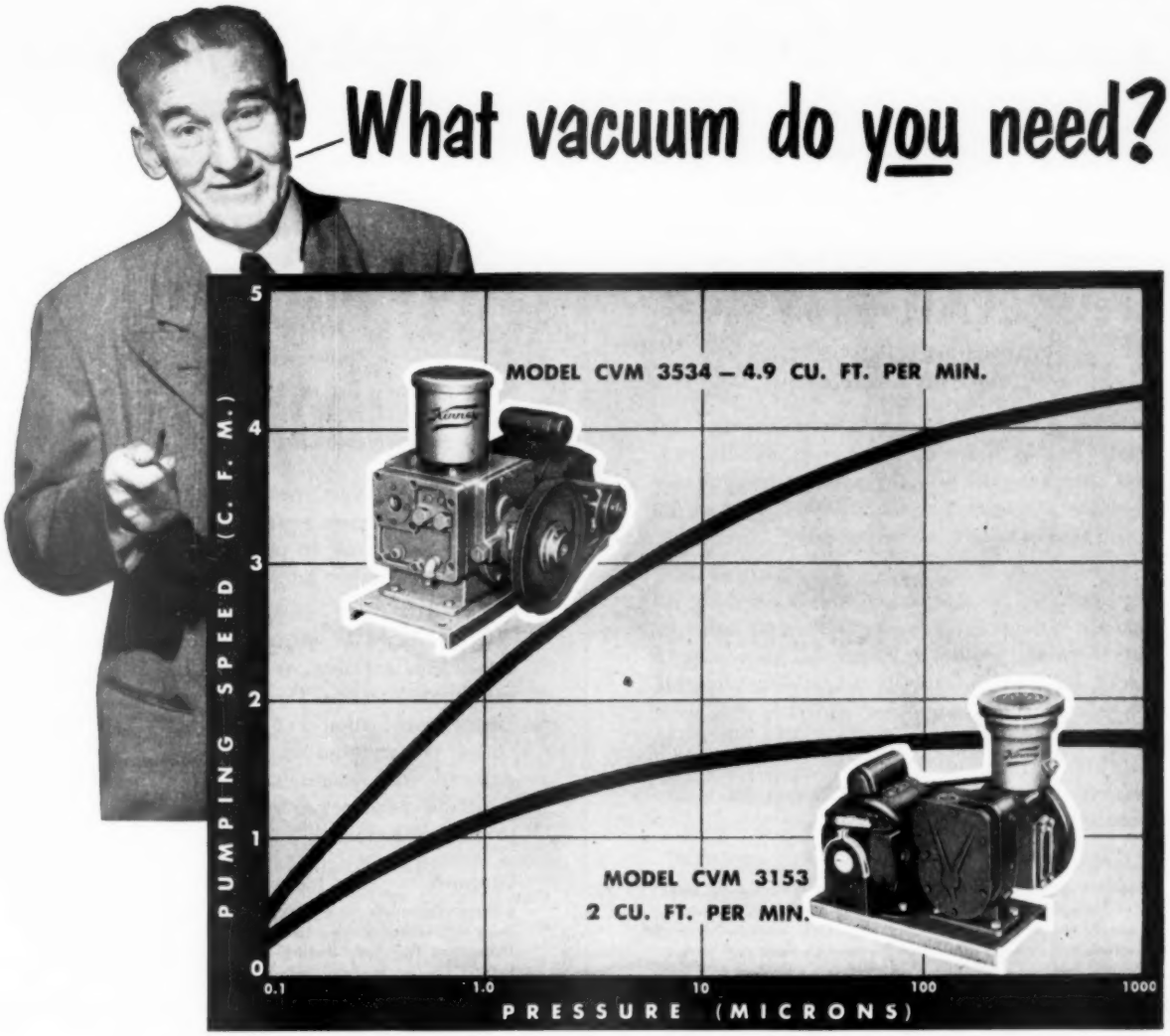

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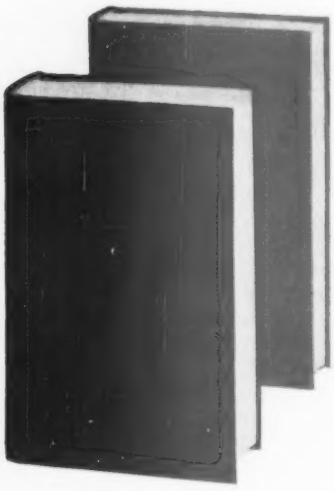

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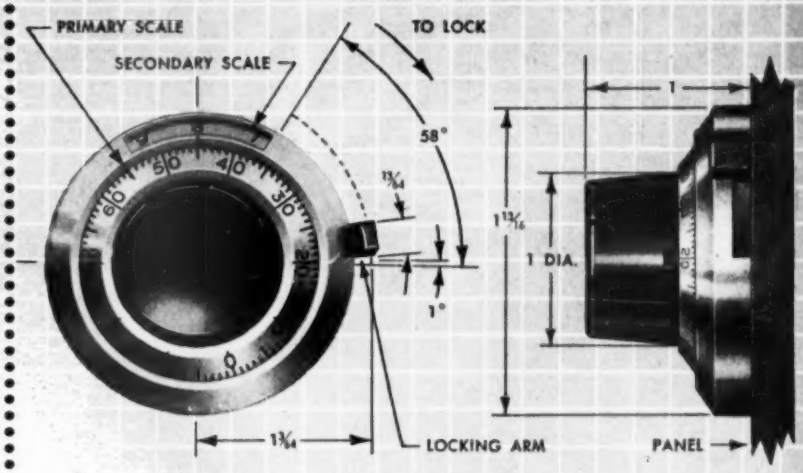

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GENERAL ELECTRIC

NUCLEONICS APRIL, 1953

Jerome D. Luntz, Editor

A "Proper Atmosphere"

WITHIN THE PAST SIX MONTHS, three proposals have been made to the Atomic Energy Commission for the development of power reactors for industrial use. Two of these plans call for the production of weapon-grade plutonium as the principal product with power as a by-product. The other has power as the principal product with fuel-grade plutonium as the by-product.

In addition, single-purpose, power-only reactors have been espoused (p. 12).

However, despite this range of ideas, weapon-grade plutonium always seems to be the protagonist in debates on nuclear power. Arguments hinge on the pros and cons of guaranteeing markets for such plutonium.

We don't at this time want to argue the merits of this problem. What concerns us is that these arguments carry over into discussions of atomic energy legislation.

THERE ARE SOME WHO CONFUSE the two questions of whether the AEC should guarantee a plutonium market to industry and that of whether Congress should change the Atomic Energy Act.

A decision to make any major change in the Act should not be based on a consideration of any specific reactor project proposal. If the AEC decides it wants to buy plutonium on a unit price basis from a private reactor owner (the Act permitting) or even from a contractor to AEC, this is AEC's own decision to make based on its feeling that it needs the plutonium and that it can justify guaranteeing a market at a set price.

Nor in evaluating legislation should we consider whether it is possible to have economic nuclear power today, tomorrow or ten years from now. No one can possibly predict what technological advances there'll be in the coming years.

Rather we should act on the basis of what our long-range objective is for the development of atomic energy. At a hearing of the Joint Congressional Committee on Atomic Energy in 1947, a Senator who is still a member of this group told David Lilienthal, then AEC chairman:

"It was the intention of Congress [in passing the Atomic Energy Act] that these extraordinary grants of power that we have given to the Government, both on the operating side and on the patent side, would be restored to private enterprise at the very first time that it can be done, consistent with safety and the national welfare."

APPARENTLY AEC FEELS this time has come. Two commissioners of the AEC have told NUCLEONICS that one of the most important reasons for changing the Act now is to create a "proper atmosphere" for fostering the development of a nuclear power industry. In addition, AEC chairman Gordon Dean feels that if the Act is changed industrial investment in atomic energy will be forthcoming in the next several years.

Dean also strongly believes that there is no reason for a "public vs private" power controversy to arise. Who builds power reactors should depend upon who has the money. As far as government agencies are concerned—whether it be the AEC or any other agency—it will be Congress that will make the decision on this in the form of action on budgetary requests.

But the important decision which must be made now is that the Atomic Energy Act must be amended to create the proper atmosphere for the growth of a peacetime atomic industry.

POWER-ONLY REACTORS—

THE DIRE[illegible]TO ECONOMIC NUCLEAR POWER

If the government is to subsidize the development of industrial nuclear power, the author feels the only way to get unequivocal cost data is by the building of single-purpose reactors

By GEORGE L. WEIL*

IN THE PAST FEW MONTHS there has been a significant increase in public interest and discussion in the field of nuclear power. Several different approaches to the development of economic nuclear power have been suggested by industrial groups and others familiar with the technical, legislative, and economic problems.

These approaches can be broadly classified as either "dual purpose" or "single purpose," depending upon whether the immediate interest is in building plants which will produce plutonium for military use and power as a by-product, on the one hand, or power only, on the other hand.

In a recent issue of NUCLEONICS,† the dual-purpose plant was discussed as an approach to the development of economic power. The purpose of this article is to present the case for the single-purpose plant.

A discussion and comparison of approaches can only be meaningful in relation to a specific concept of the long-range objectives of a nuclear power development program, to a broad picture of how the industry might develop, and to a definition of immediate objectives.

It is assumed that:

1. *The long-range objective is to develop competitive industrial nuclear power which can, in time, contribute substantially to the energy requirements of the United States.*
2. *Nuclear power in the U. S. will not be subsidized beyond the very early stages of its growth.*
3. *The extent of industrial use of nuclear power will show a gradual growth determined primarily by the practical costs of nuclear power and the competitive market for power at those cost levels.*
4. *Although estimated nuclear power costs are now high compared to average U. S. power costs, an adequate technical and engineering development program can eventually reduce these costs to make the long-range objective a realistic one.*

It is assumed that nuclear power will not be in a position to provide a substantial amount of the U. S. energy demands for at least 20 or 25 years because of the estimated present differential between nuclear and average conventional power costs; because of the anticipated negligible rise in cost of power from conventional plants in the next 25 years or so; because of the nature of the technical and engineering problems which must be solved to provide further reductions in nuclear power costs; and finally, because of the effort and costs involved in developing and building new types of nuclear power plants.

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† Carroll A. Hochwalt, Philip N. Powers. Dual-purpose reactors: first step in industrial nuclear power development, NUCLEONICS **11**, No. 2, 10 (1953).

From the short-range point of view it is assumed that:

1. *The present estimated level of unsubsidized nuclear power cost is such that it is within shooting distance of competing with conventional plants in high-cost areas.*

2. *The short-range objective is not only to make a substantial step toward getting a nuclear power industry started, but also to start it in such a way that it will continue to grow as a result of normal economic incentives.*

The major factors which will determine whether the industrial use and development of nuclear power can be launched on a self-sustaining basis are: first, that there are no fundamental technical or engineering reasons preventing the reduction of nuclear power costs to a practical level; second, the demonstration that nuclear power can within a short time compete economically with conventional plants in a limited number of areas; and finally, that legislative and governmental policies will be such as to promote the development of nuclear power.

Pattern of Industry Growth

A general picture of growth of a nuclear power industry involves five major assumptions. First, a power industry will be based on single-purpose power-only plants.* Second, nuclear power costs are unlikely ever to be competitive on a significant scale unless the fuel costs have been made negligible. Third, for uranium costs below a certain value, there is no reason to believe that fuel costs for regenerative-converters cannot, with further development, be made essentially negligible. Fourth, though the operation of plutonium breeders may be based on the use of very cheap raw materials, there are processing operations involved in the utilization of the fuel which must be reduced in cost if the over-all fuel cost is to be negligible. Finally, regenerative-converters are today further advanced technically and engineeringwise than are breeders.

Three broad steps are envisaged in this growth pattern:

Phase 1. Nuclear power will compete on an increasing but still relatively limited scale in high-cost areas. It is assumed that in this period converter reactors with substantial regeneration of fuel will be the basis of design for the nuclear power plants.† Perhaps the most characteristic aspect of Phase 1 is that the market for nuclear power will not be so large as to result in significant increases in the cost of raw materials (uranium).

Phase 2. The growing raw materials demand will require expansion of mining operations to lower grade ores which, in turn, will raise the cost of the raw material. By this time, it is assumed that breeder reactors, based either on the thorium-U^{233} or the U^{238}-plutonium cycles, or both, will have been developed to the point when they can compete economically with the more highly developed regenerative-converters. In Phase 2, therefore, one would expect to find a gradual shifting of the nuclear power load from regenerative-converters to breeders. However, it is assumed that substantially all the plants, both regenerative-converter and breeder types, will be single purpose.

Phase 3. Substantial amounts of nuclear power will be produced, almost wholly by breeders. Even in this period, however, regenerative-converters will be economically attractive to the extent determined by the availability of ordinary or slightly enriched uranium at sufficiently low costs. Such converter plants might be utilized in special situations for which they are better adapted than breeders.

The Cost Question

To have such a growth pattern, economic incentives should be brought into play at an early date for further development and growth of a nuclear power industry.

Whether this nuclear industry is to be publicly or privately owned, it is essential to obtain an early answer to the question of cost. Only intensive efforts to obtain the lowest unsubsidized nuclear power costs on the basis of present technology can show whether the time is right for the industry to grow on a self-supporting basis.

The single-purpose approach would provide this information unequivocally by permitting the design of the plant for power production only. Since several basic types appear to be equally attractive within the present precision of power cost estimates, it would be desirable to construct more than one single-purpose plant based on different designs.

The single-purpose approach would focus its efforts on two major problems:

1. *Reduction of plant investment costs per kilowatt of generating capacity.*

2. *Reduction of fuel costs by increasing fuel utilization.*

There are no easy solutions to these problems. In both areas significant improvements will be achieved in the long run only through intensive research and development and imaginative engineering efforts.

The dual-purpose plant has been suggested as an alternate approach. Briefly, this approach proposes to market nuclear power at a cost competitive with present power costs from large conventional plants by also producing and selling to the government plutonium for military use. Whether or not such a dual-purpose plant is economically advantageous from the point of view of the nation's plutonium production program will not be considered here. The purpose here is to compare it with the single-purpose approach in terms of developing economic nuclear power.

If one accepts the validity of the earlier statement concerning the nature of the information needed at this time, then unquestionably a direct attack on the major technical and engineering problems which now stand in the way of lower production costs would provide the most effective approach.

No one has ever suggested that the best way to develop a nuclear power plant for submarine propulsion is to first build one that can simultaneously do one or more things with power for propulsion as a byproduct. So any suggestion to bypass the direct attack on economic power must be based on reasons other than those of a technical or engineering nature.

The two approaches have certain features in common. First, they are both technically feasible. Second, either plant, if authorized for construction in the relatively near future, would be of the regenerative-converter type. Third, they would both involve the expenditure of substantial funds for research and development effort and for

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* ". . . hope for nuclear energy as a more or less permanent economical source of power must rest on the straight power reactor and the breeder reactor." Philip Sporn, President, American Gas and Electric Co. From talk delivered before National Industrial Conference Board, New York, N. Y., Oct. 16, 1952.

† Regenerative-converter reactors are distinguished from breeders in that they are designed to utilize U^{235} as fuel rather than Pu or U^{233}. In the process of consuming the U^{235}, they will regenerate fuel material in the form of Pu and/or U^{233}.

design and construction. Fourth, each, by appropriate financial arrangements, could encourage and obtain industrial participation. Finally, before private risk capital could be considered for financing the construction of either type of plant, changes in the Atomic Energy Act would be required.

Financing Early Plants

The most striking distinction between the single- and dual-purpose approaches is the method proposed for financing the over-all operation. Because it is not expected that the straight cost of producing power from early nuclear plants will be competitive or economic as an industrial operation in the United States, some form of financial support will be required. The single-purpose approach would require a direct government subsidy, assuming that the plant is not wholly financed by nonprofit organizations (including the government) as an experimental or development project.

On the other hand, the basic argument in support of the dual-purpose approach is that the financing would be "economically sound." The economic soundness of this approach clearly depends upon a continued high military value placed on plutonium production. For the purpose of this article, it must be assumed that this will be the case, otherwise the "raison d'être" for the dual-purpose approach vanishes.

Information Obtainable

The comparison now resolves itself into inquiring whether both approaches would provide the same information, technical and economic, which would represent a substantial step in the development of industrial use of nuclear power. By definition, the single-purpose approach is directed solely toward obtaining this information in the most effective way and in unequivocal terms. On the other hand, though the dual-purpose approach may represent an immediate attractive proposition based on current military needs, the question arises will sound information be sacrificed for "sound" financing?

Intuitively one would expect that any approach which subordinates the product of major industrial interest to the product of military interest would of necessity fail to provide as satisfactory information as would an approach directed solely toward the product of major interest. And this expectation is supported by more detailed considerations.

For example, there are administrative and operational differences which would make difficult any attempt to separate and allocate costs associated with a dual-purpose plant to provide information on power costs as such, and the significance of the results would be doubtful.

Design for Power or Pu?

More important, there are stages in the design and engineering of a plant at which conflicts will occur, and decisions will be made which will sacrifice or compromise the short-range objectives of minimizing investment costs and prolonging fuel life. The extent of the compromise might well depend on the type of basic design selected for the dual-purpose reactor. Even though no one conflict may be determining, certainly the accumulation of many small design decisions can have a significant effect on the economics and efficiency of power production.

The conflicts arise as the result of the relatively high value which is attached to the plutonium production as compared to the power production. Because a major area of development for economic nuclear power is in the reduction of investment costs per kilowatt of capacity, it is to be expected that optimization for plutonium production and low unit costs for that product will interfere with realizing similar objectives for power.

It should not be surmised from the following superficial discussion that the selection of major components and the detailed design of the reactor system can be considered separately in optimizing for either plutonium or power production. Clearly, the fixing of one parameter will affect the selection of other parameters. In general, it is difficult to determine the specific effect of parametric changes on over-all performance without carrying through detailed calculations. For the purpose of this article, only first-order effects will be discussed.

Dual-purpose design. *For a dual-purpose plant, the selection of components and plant design must optimize conditions for plutonium production.*

According to Hochwalt and Powers, "Because of the high cost of plutonium, the reactor should be designed and operated so as to produce it as cheaply as possible regardless of the effect on the efficiency of the power production." Thus, very high power levels would be selected to take full advantage of economies that can be realized for larger plants. Because of the variation in neutron-absorption characteristics of the available moderators, structural materials, and coolants, the particular choices made can have significant effects on the efficiency of plutonium production. Finally, since the fuel must be discharged periodically to provide weapons-grade plutonium, aspects of the basic design that might interfere with this operation must be considered. Clearly the plant shutdown time for fuel replacement must be kept to a minimum.

Power-only design. *A different emphasis is placed on the design parameters of the power-only reactor.*

The size or total power output of the plant would most likely be determined by practical considerations of generating requirements. The production of plutonium in the fuel element is a desirable characteristic in the design of a power-only reactor since it may determine both the over-all utilization of the raw material and the extent to which the fuel can be used before reprocessing is required. However, the effects of neutron absorption of materials in the reactor are not as critical in optimizing for power production as for plutonium production. Finally, since consideration need not be given to relatively frequent routine discharging of the fuel to remove weapons-grade plutonium, the selection of coolant and design of the coolant system can be based on factors directly related to optimization for power production.

Detailed considerations. In the more detailed design of a plant for plutonium and/or power production, the following parameters must be specified:

1. Diameter or thickness of uranium fuel elements.
2. Volume ratio of moderator to fuel.
3. Enrichment of fuel.
4. Material and thickness of cladding material for the uranium.
5. Maximum temperature of fuel and structural materials.

6. Inlet temperature of the coolant.
7. Exit temperature of the coolant.

The fixing of these parameters will, in turn, determine the major operating characteristics:

1. Total thermal power output.
2. Total plutonium production capacity.
3. Thermal efficiency and electric power output.

Critical design parameters. Although the amount of heat energy released is fixed for every pound of fuel consumed in a reactor, both the amount of plutonium and the amount of useful power produced for the same fuel consumption can be varied over wide ranges through variations of the design parameters.

In a dual-purpose plant, the critical design parameter is the *conversion ratio*, which determines the relative amount of plutonium produced per unit of fuel consumed. In the design of a plant for power only, the critical parameter becomes the *specific power*, or power produced per unit amount of fuel.

For a given total thermal power, the *conversion ratio* and the *specific power* of a reactor are directly related in such a manner that as one is increased the other must decrease. This relationship is obvious when one considers that as the fuel is subdivided to provide more heat transfer surface and thereby higher specific power, the amount of cladding material in relation to the amount of uranium increases. Since the cladding material absorbs neutrons that would otherwise be available for plutonium production, the conversion ratio must decrease. Whereas a high conversion ratio is important for the dual-purpose plant, a high specific power assumes more importance for the power-only reactor. For the latter, this essentially means a low uranium inventory and a small reactor plant.

In considering the design of a dual-purpose plant, emphasis must be placed not only on designing for high conversion ratios but also on designing for high rates of plutonium production. Since the rate of plutonium production is proportional to the rate at which heat can be removed from the plant, a large temperature driving force between the fuel element and the coolant is desirable. Thus, for a given maximum temperature for the fuel or structural materials, the lower the coolant inlet and exit temperatures the better the plant. On the other hand, for obtaining useful power production at lowest unit cost, design would go in the direction of high coolant exit temperature in order to take advantage of the higher thermodynamic efficiencies in converting the thermal energy into electric energy. Although some designs for coolant and heat exchanger systems may circumvent this conflict, it is not clear that this can be done without at the same time increasing the cost for plant and equipment which would, in turn, increase over-all production costs.

Engineering considerations. It is reasonable to expect that, as a result of the value placed on weapons-grade plutonium from a dual-purpose plant, the engineering of the plant will differ from the engineering of a power-only plant.

First, there will be a tendency to over-design plant and equipment to ensure reliability of operation and to minimize delays in getting the plant up to production capacity and in lost production time due to forced shut-downs. Even more important, the reactor would have to incorporate special equipment and design features which would provide rapid charging and discharging of fuel. These added design features will not only have a significant effect on the capital cost of the plant per kilowatt of generating capacity, but also, because they are inextricably tied into the over-all design, their effects on the production cost of power could not be effectively separated out.

Will the dual-purpose approach provide any technical information directly related to the development of economic power which would not also be provided by the single purpose approach?

It is extremely unlikely, since both are considered as plants which could be designed and constructed within the next few years. Though much could be done in making most effective use of the basic technical and engineering information that is now available, it is difficult to visualize how either approach would add significantly to the present reservoir of reactor technology.

Definition of Dual Purpose

Hochwalt and Powers suggest that the dual-purpose reactor of today is a prototype of the power-only breeder of the future, "since a breeder is really a dual-purpose type of reactor." This broad definition of dual purpose covers every reactor that produces power and contains fertile material, i.e., uranium-238 or thorium-232. It includes the regenerative-converter if designed and used as a power-only plant, and it covers the uranium-233 and the plutonium power breeders.

The distinction between this broad definition and the generally accepted one is essentially the difference in value that is attached to the plutonium in the two cases. The single-purpose plant will certainly produce plutonium as a necessary part of its operations. But there may be no need to separate this plutonium from fuel elements. If it were separated, it would not have military value but a significantly lower value as a nuclear fuel.

Thus, the identical basic type of reactor, whether it is a regenerative-converter or a breeder, can be dual purpose or single purpose depending upon whether the plutonium that is produced is valued in the over-all economic feasibility of the plant operation as a material for military use or as a fuel for industrial power use.

The strict definition of the term dual purpose has been used in the discussion of this article. The fact that power-breeders are dual-purpose plants under the broad definition does not mean that the dual-purpose approach is necessarily either technically closely related to the development of breeders or more so than the single-purpose approach.

Possible Foreign Use

To conclude the case for the single-purpose approach on a positive note, the power-only plant has two important additional features not found in the dual-purpose plant.

First, because the size of the plant is not determined by considerations of military production requirements, it would be possible, if desired, to keep both the investment in plant and equipment and the annual cost of subsidy to moderate proportions.

Second, since the cost of power from conventional plants in foreign countries is on the average higher, and in some areas considerably higher, than in the United States,

(Continued on p. 60)

Delayed Photoneutrons in a Heavy-Water Reactor

IN REACTOR EXPERIMENTS that take a day or less, some of the delayed photoneutrons from the disintegration of the deuterons in heavy water are equivalent to a constant neutron source. At intermittent steady-state operation of the reactor, the excess effective multiplication factor must, as a consequence, be considered negative and dependent on the power level of the reactor.

If an excess reactivity is suddenly injected into the reactor, the amplitude of the initial fast increase in power will depend on the amount of long-lived photoneutron activity built up, and thus on the history of the fuel elements in the reactor.

The Photoneutrons

One of the main differences between the delayed neutrons emitted by the fission products of uranium and the delayed photoneutrons produced in heavy water by high-energy γ-rays from the fission products is the long decay time of the delayed photoneutrons (*1*, *2*). The delayed neutrons which follow directly the emission of β-particles by fission products usually follow decay times which lie within a limited range (0.1 to 100 sec). The delayed photoneutrons may, on the other hand, follow isomeric transitions of very short half-life, or they may follow β-decay of very long life-time.

The only photoneutron period which, to our knowledge, has been assigned to a specific fission product is the 12.8-day period of the high energy γ-ray from La^{140} (*1*). The La^{140} occurs in transient equilibrium with Ba^{140}, which has a cumulative fission yield of 6%. The disintegration of La^{140} leads, in 4% of the cases, to the emission of high-energy γ-rays, which are responsible for the photoneutrons (*3*). If we, for the time being, consider this single source of photoneutrons, which also has the maximum known decay time, we can roughly estimate its contribution to the neutron density in the reactor.

The probability that the γ-ray is captured by deuterium in the reactor is of the order of 10^{-3}. The number of photoneutrons emitted per neutron released in fission is therefore $\frac{1}{2}(1/2.5)0.06 \times 0.04 \times 10^{-3}$, where the factors $\frac{1}{2}$ and $1/2.5$ occur because the total fission yield is taken as 200% and the total number of neutrons emitted in fission is 2.5. With these data, one can therefore predict that if a heavy-water reactor has been running at a power P for a few months, the shut-down power due to the photoneutrons from the La^{140} γ-rays will be of the order of $5 \times 10^{-7}P/(1-k)$, where k is the effective multiplication factor of the reactor at shut-down. In the case of JEEP, $k \simeq 0.978$. The shut-down power level due to the La^{140} γ-rays was 2–3 watts at the end of January, 1953. The reactor had been running intermittently for a few weeks at 200 kw. The photoneutrons due to the La^{140} γ-rays had therefore not yet reached equilibrium intensity.

Bernstein *et al.* (*2*) have reported that a delayed γ-emitter among the fission products, with a half-life of about 2 days, also produces photoneutrons in heavy water. According to our estimates, it should contribute to the neutron flux about twice as much as does the La^{140}.

It is interesting to note, on the other hand, that the coefficient for conversion of high-energy γ-rays into photoneutrons in the reactor can be determined experimentally by measuring the shut-down flux of neutrons due to a known γ-emitting fission product. Although the contribution to the neutron flux due to the delayed neutrons is nearly independent of the geometry and detailed structure of the reactor, this is not the case with the photoneutrons.

A figure for the correlation between different reactors or between a specific reactor and the idealized experimental results on photoneutron yields in an infinite sphere of heavy water by a very small sample of fission products can be obtained by measuring the photoneutrons due to the La^{140} γ-rays. However, since the energy of photoneutrons with different periods varies, this procedure is only approximately correct. This will lead to an inaccurate relationship between reactivity and doubling time for the reactor power. According to our experience, however, the error introduced in this way is small compared to the errors in the delayed-neutron data.

Effect on Reactor Operation

In this discussion of reactor kinetics we will assume that the neutron density in the reactor can be represented as a product of a space- and a time-dependent function. Temperature and neutron poison effects will be neglected. If the excess effective multiplication factor is k_{ex}, the rate of change of the thermal-neutron density in the reactor will be

$$\frac{dn}{dt} = \frac{k_{ex}}{l}\, n - \sum_i \frac{dc_i}{dt} + S \qquad (1)$$

where l is the average life-time of a neutron in the reactor and S is the strength of a neutron source. The term c_i is the density of the ith delayed-neutron emitter (including delayed photoneutrons), and obeys the equation

$$\frac{dc_i}{dt} = \frac{\beta_i k_{ex}}{l}\, n - \lambda_i c_i \qquad (2)$$

where λ_i is the decay constant.

According to Eqs. 1 and 2, the reactor is in a steady state when

$$n = n_0 = -\, lS/k_{ex}{}^0 \qquad (3)$$

The critical condition is obtained when $k_{ex} = 0$. We have then

$$d(n + \textstyle\sum_i c_i)/dt = S$$

Fission-product gamma rays acting on the heavy-water moderator makes it a neutron source. The effect of these neutrons on reactor kinetics is described. For JEEP, photoneutrons correspond to about 0.04 watts a few days after shut-down

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and therefore we find the relation

$$n + \sum_i c_i = St + \text{constant}$$

Thus the neutron density increases slowly with time. Only for $S = 0$ will the critical condition correspond to the steady state of the reactor. In practice, S can be neglected if, according to Eq. 3, it contributes to the effective multiplication factor by an amount which is much less than 10^{-5}.

In a reactor moderated with graphite, the background source of neutrons is mainly due to the spontaneous fission of natural uranium (corresponding to about 2×10^{-13} watts/gm), with a small contribution from cosmic rays. When such a reactor is operated at a power level of a few watts, or higher, the source term can be neglected for all practical purposes.

In a reactor moderated with heavy water, the long-lived high-energy γ-emitters, which are responsible for the photoneutrons will, once they have been built up, be equivalent to a neutron source in many experimental situations. They appear somewhat like an inverse neutron poison effect.

If the contribution of the long-lived photoneutrons to the total neutron production at saturation is

$$S = -k_{ex}{}^0 n_0/l \qquad (4)$$

where $-k_{ex}{}^0$ is a coefficient of the order of 10^{-6}, the rate of emission of photoneutrons at shut-down is $S/(1-k)$. If the reactor power is changed to a new value, corresponding to the neutron density n, the instantaneous steady state condition will now, according to Eqs. 3 and 4, give for the excess effective multiplication factor

$$k_{ex}/k_{ex}{}^0 = n_0/n \qquad (5)$$

Some measurements of JEEP (*4*) on January 27, 1953,* gave the following results. With the horizontal cadmium control rod withdrawn 34 cm, the doubling time of the reactor with all the vertical cadmium plates in the out position (0 cm) was 42 sec. This corresponds to $k_{ex} = 0.00129$. At 5 kw, the K2 control plate had to be raised 83.7 cm to obtain a steady-state operation. The absolute value of the excess reactivity was then less than 10^{-5}. At 1 kw and 500 watts, the K2 position was 84.6 cm ($k_{ex} = -4 \times 10^{-5}$) and 85.9 cm ($-8 \times 10^{-5}$), respectively. At 100 watts, $k_{ex} = -40 \times 10^{-5}$, and at 1 watt, $k_{ex} = -400 \times 10^{-5}$. The steady photoneutron source corresponded, in this case, to about 0.04 watts.

Influence on Power Change

We will finally analyze the influence of the delayed photoneutrons on the variation of reactor power following a sudden change in reactivity. If we solve Eqs. 1 and 2 for this case, we find that the neutron density, and thus the reactor power, increases rapidly (time constant, a few tenths of a second) immediately after the reactivity is changed. The steep rise lasts for about 1 sec, and then a slower variation sets in. After about a minute, the divergence follows the so-called stable period.

The effect of the photoneutrons is to magnify the amplitude of the initial rise and to change slightly the time behavior of the following slow increase.† Strictly speaking, a stable period is never reached, due to the long-lived photoneutrons and the perturbation of the temperature effect on the reactivity. Since the effect of the delayed photoneutrons is most striking initially, we will consider in some detail what happens the first few tenths of a second after the reactivity is suddenly changed.

As initial conditions at $t = 0$ we have

$$n = n_0 \quad \text{and} \quad \sum_i \lambda_i c_i = \frac{k\beta}{l} n_0 \qquad (6)$$

If we consider a time that is short compared to the decay time of the delayed-neutron emitters, we can assume that the emission of delayed neutrons stays constant. Then, according to Eqs. 1, 2, and 6,

$$\frac{dn}{dt} = \frac{k_{ex} - \beta k}{l} n + \frac{\beta k}{l} n_0 + S \qquad (7)$$

Physically, this equation means that during the first moments after the reactivity is suddenly changed, the excess multiplication factor is $k_{ex} - \beta k$; the delayed-neutron emitters formed earlier and the source continue to emit neutrons at a constant rate. The solution of Eq. 7 with the initial conditions, Eq. 6, give

$$n = \frac{\beta k n_0}{\beta k - k_{ex}} \left\{ 1 - \frac{k_{ex}}{\beta k} \times \exp\left(- \frac{\beta k - k_{ex}}{l} t \right) \right\} + \frac{Sl}{\beta k - k_{ex}} \times \left\{ 1 - \exp\left(- \frac{\beta k - k_{ex}}{l} t \right) \right\} \qquad (8)$$

Thus

$$n_{t \to \infty} = \frac{\beta k n_0 + Sl}{\beta k - k_{ex}} = \frac{(\beta k - k_{ex}{}^0) n_0}{\beta k - k_{ex}} \qquad (9)$$

where $k_{ex}{}^0$ is the excess multiplication factor at $t \leq 0$ (Eq. 3). Thus we see that the amplitude of the initial fast rise in neutron density increases linearly with the intensity of the long-lived photoneutron source.

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* The reactor had been shut down 2 days earlier, and previous to that had operated at 200 kw for several weeks.

† These results have been experimentally verified by N. Holt and the author.

Measurement of Turnover Rates in Systems of Hydrodynamic Pools Out of Dynamic Equilibrium

In preparation for turnover rate studies in living organisms, effective tracer measurements of such rates have been made using a "model" pool and simple systems of pools. With the methods described, dynamic equilibrium need not be assumed nor velocity functions used

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INTEREST in the measurement of turnover rates by tracer methods has increased progressively during the past two decades as isotopic tracers for most of the stable elements became available. With radioisotopes now in abundant supply for compounding tracer material, the limiting factor in the measurement of turnover rates now appears to be the ability to design, perform, and analyze experiments suitable for such measurements.

Throughout the initial period of application of tracer methods to turnover rate calculations, the validity of tracer-determined rates has not been established through comparison with directly measured values. Recently, Zilversmit and Shore (*1*) made such a comparison, using an open system of two hydrodynamic pools assumed to be in dynamic equilibrium and bromsulfalein dye as a tracer, by which they convincingly demonstrated the applicability of the particular tracer and tracer method employed.

During the past year experiments of the same general nature were conducted at this laboratory as a preliminary step toward applying the same tracer procedures for rate determinations to networks of metabolic pools in living systems. Absolute turnover rates in as many as four hydrodynamic pools have been measured simultaneously using an aqueous solution of crystal violet dye as a tracer. The calculated rates were compared with corresponding ones measured directly.

Basis of Measurement

The only premises upon which the analyses were based were that the tracer substance did not modify or respond differently to the water with which it was mixed and that both tracer and water were conserved. No inferences were made concerning the applicability of velocity constants (*2*) or the nature of metabolizing functions (*3*), and dynamic equilibrium was not assumed to exist at any time.

The exchange of a chemical entity A between each of n metabolic pools with all of the other $n - 1$ pools has been described in mathematical terms by Sheppard* (*4*), but not in terms of rates. The following $2n$ simultaneous equations hold true at all times in a network of n exchanging pools in all systems in which mass is conserved

$$\frac{dN_j}{dt} = \sum_{k=1}^{k=n} (R_{kj} - R_{jk}) \qquad (1)$$

$$\frac{dN_j^*}{dt} = \sum_{k=1}^{k=n} (R_{kj}^* - R_{jk}^*) \qquad (2)$$

where, in each case, $k \neq j$. N_j and N_k represent the total numbers of units of an element A in the jth and kth pools, respectively, at any time t. R_{kj} and R_{jk} represent the rates of transfer of units of element A from pool k to pool j,

* In the same paper, Sheppard also suggests the use of dyes as suitable tracer substances for hydrodynamic systems, as well as the use of procedures involving graphical integration like those employed in the analyses of our data.

and from pool j to pool k, respectively, at time t. The integers j and k can have any value from one to n inclusive. Symbols marked with asterisks in Eq. 2 have the same connotation as described above, but refer to labeled units of element A.

By definition, the absolute specific activities γ_j and γ_k of element A in pools j and k will then be, respectively

$$\gamma_j \equiv \frac{N_j^*}{N_j} \quad \text{and} \quad \gamma_k \equiv \frac{N_k^*}{N_k}$$

If perfect mixing of the labeled and unlabeled A units occurs in each pool, it also follows that

$$\gamma_j = \frac{R_{jk}^*}{R_{jk}} \quad \text{and} \quad \gamma_k = \frac{R_{kj}^*}{R_{kj}}$$

at any time t, where $k \neq j$.

It follows from these relations that Eq. 2 can be written

$$\frac{d}{dt}(\gamma_j N_j) = \sum_{k=1}^{k=n} (\gamma_k R_{kj} - \gamma_j R_{jk}) \quad (3)$$

where $k \neq j$.

Equations 1 and 3 represent the bases for all rate determinations made in this paper. In systems where the experimenter has access to each of the metabolic pools, it is possible to measure γ and N for all pools at a sequence of times throughout the experiment, from which values for $d\gamma/dt$ and dN/dt can be determined for every pool at the same sequence of times.

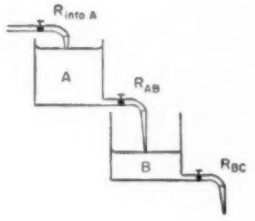
All values of R_{kj} and R_{jk} at any selected time or over any finite interval of time can be determined from these data, using Eqs. 1 and 3 for all networks including three or fewer pools, regardless of whether or not a condition of dynamic equilibrium exists. It is also possible to solve for all rate values in such networks with more than three pools if some of the rates are known. If, for example, four or more of the twelve possible pathways between a network of four pools were known to be closed, it would then be possible to determine simultaneous values for each of the remaining rates at whatever time interval or times during the course of the observations such values are desired.

Experimental Data

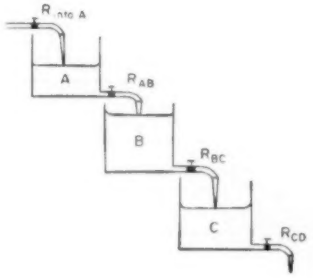
Although different procedures for determining rates of inflow and outflow for each pool in a given system were

FLOW RATES (ml/min)

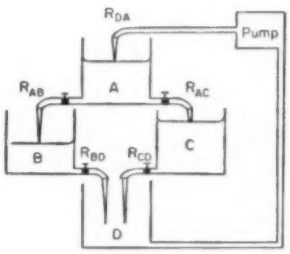
Position where rate determined	Measured		Calculated	
	Time interval 1	Time interval 2	Time interval 1	Time interval 2
$R_{into\ A}$	109.4	108.2	111	113
R_{AB}	104.4	101.2	106	107
R_{BC}	100.6	98.1	102	103

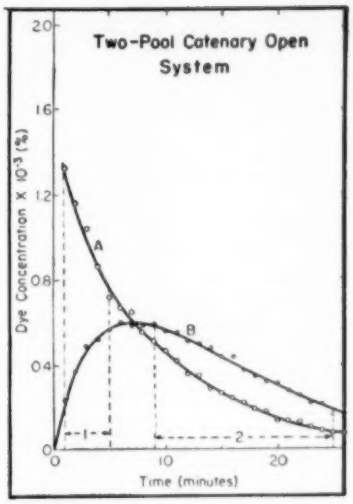


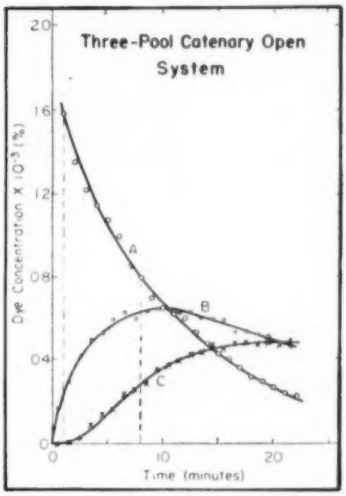
	Measured	Calculated
$R_{into\ A}$	65.7	67
R_{AB}	64.6	66
R_{BC}	65.5	67
R_{CD}	68.1	70



	Measured	Calculated
R_{AB}	76.5	82
R_{AC}	66.2	69
R_{BD}	76.8	82
R_{CD}	64.9	68
R_{DA}	159.0	129







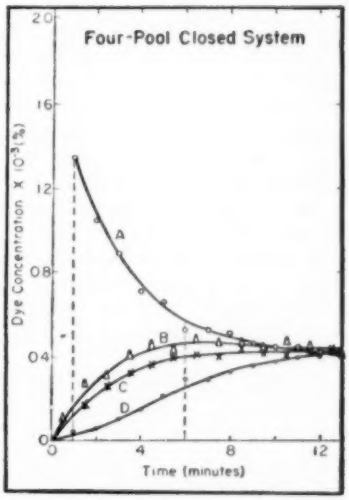


FIG. 1. Systems of hydrodynamic pools studied, with corresponding curves of dye concentration (γ) versus time. The "measured" values were measured directly; the "calculated" values were derived from tracer methods

investigated, only those values obtained with what appeared to be the most effective of these procedures are shown in Fig. 1.

The agreement between directly-measured and tracer-measured (calculated) rates is found to be close in each case, demonstrating that the theoretical basis, the observations taken, and the methods of analysis employed were adequate for the measurement of absolute turnover rates in the systems of pools investigated. The rate determinations made by dye tracer in a single hydrodynamic pool are likewise found to be closely comparable to the directly measured ones, regardless of the type or arbitrary rate changes occurring during the experiment. See Fig. 2.

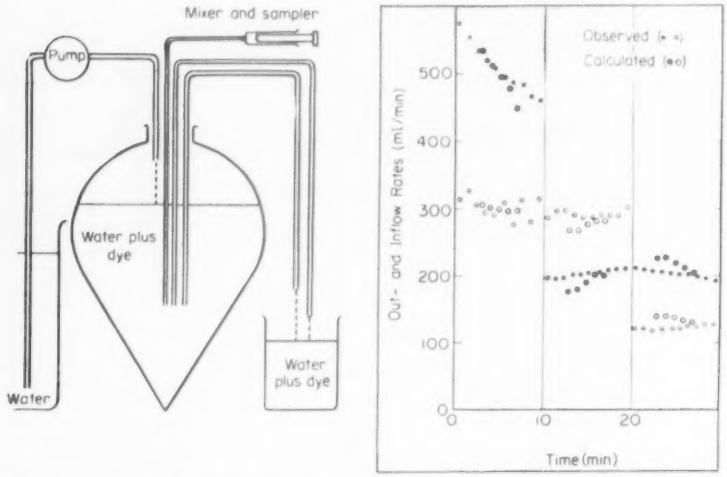


FIG. 2. Plan of a single hydrodynamic pool of complex shape in which directly-measured and tracer-calculated rates of inflow and outflow were compared using crystal violet dye as a tracer. Sudden and large changes in outflow and inflow rates were made at 10 and 20 minutes, respectively, while small continuous changes occurred at other times

The direct and indirect rate measurements in Fig. 2 are sufficiently precise to demonstrate slight but characteristic differences which might be compared to reaction rate differences that are frequently observed with and resulting from differences in isotopic tracers (*5*).

In all of our experiments with the single pool, the directions of these differences are those which would be expected if some dye were first adsorbed onto solid surfaces from the circulating water when the dye concentration was high and then released once more at low dye concentration, allowance being made for the effect of changes in turnover rate of the water in the pool.

This "adsorption" effect was found to be greatest when fast green dye was used as tracer, much less when bromsulfalein was employed, and least obvious using crystal violet dye.

Should Equilibrium Be Assumed?

Demonstrations that tracer methods are applicable in absolute rate determinations with no reservations made concerning dynamic equilibrium are reassuring and should stimulate further interest in this particular type of measurement.

However, measurements made in the absence of dynamic equilibrium also illustrate an important feature of another kind. Numerous experimental studies, following the initial ones of Schoenheimer and his associates (*6*), have clearly demonstrated the existence of that state of flux of most constituents in the depots of the living body. Nevertheless it appears probable that the concept of dynamic equilibrium has been overstressed in attempts to make precise rate determinations, or to facilitate the development of mathematical descriptions of the phenomena of homeostasis with corresponding neglect of the equally important physiological phenomena of adaptation and growth which only appear and are measurable when dynamic equilibrium does not exist.

Pollard (*7*) recently suggested that complementary phenomena exist in the biological sciences on which simultaneous measurements can be made only to within a certain finite limit of error, a relationship analogous to the Heisenberg uncertainty principle established for the physical sciences. It appears that such a relation exists between the phenomena of homeostasis and adaptability in metabolic pools.

The more closely the condition of homeostasis (through dynamic equilibrium) is approached, the more accurately can the associated average turnover rate [= 0.5 (inflow rate + outflow rate)] in a given pool be measured, and, simultaneously, the less are growth or adaptation, as measured by rate of change of pool size, in evidence. Since the capacity of a metabolic pool to become adapted to a change in environmental conditions (i. e., to a change in inflow or outflow rate, or both) is a general characteristic of open systems, the importance in the biological sciences of *simultaneous* measurements of turnover and adaptation rates in the pools of such systems is obvious.

Nature confronts the biological and physical sciences with *systems* of continuously exchanging pools that conform only rarely to a precise and fixed pattern of dynamic equilibrium. The demonstration that rate measurements can be made in such systems using single-tracer procedures without seriously disturbing the dynamic phenomena under study is of basic importance.

* * *

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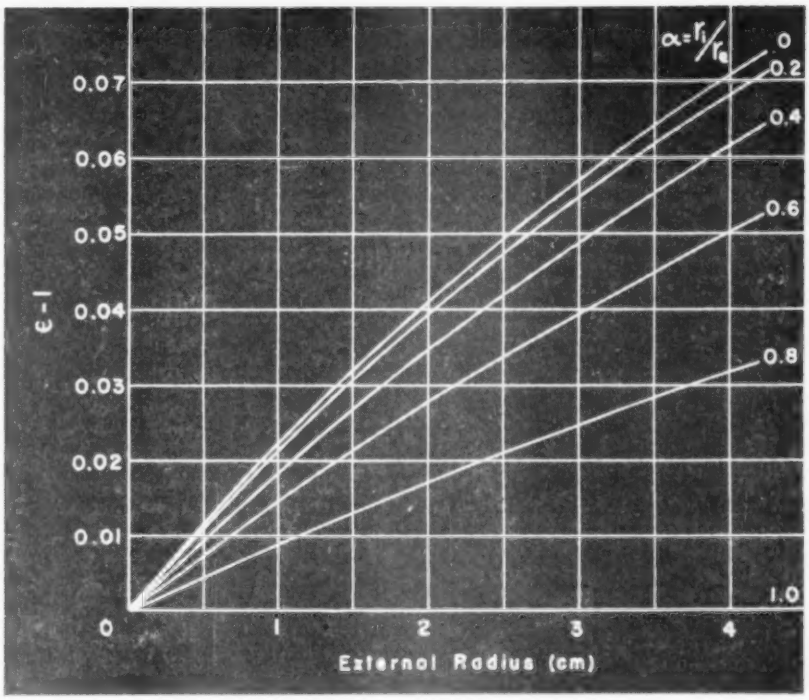

FAST FISSION FACTOR as a function of external rod radius for five values of ratio of internal to external radius

Fast Fission Factor for Hollow Natural Uranium Cylinders

For accurate calculation of a reactor's multiplication factor, the effect of fast fission must be included. The results presented will be of use in design of reactors in which coolant flows through a central duct in the fuel rods

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THE MULTIPLICATION FACTOR of a nuclear reactor, expressed by the familiar "four-factor formula" $k_\infty = \epsilon p \eta f$, is the ratio of the number of new neutrons to the number at the start of a cycle.

If k_∞ for a particular mixture of uranium and moderator is less than unity, a chain reaction cannot be made self-sustaining, regardless of the size of the accumulation of fissionable material; if k_∞ is sufficiently above unity to allow for neutron leakage from a finite assembly, a reactor may be built of this mixture.

Values of the factors that go to make up k_∞ may be computed separately. The fast fission factor, ϵ, is the measure of the multiplication of fast neutrons by fission. The factor η is the average number of fission neutrons released per absorption of thermal neutrons in uranium; f is the fraction of thermal neutrons that are absorbed in uranium;

Advantages of Coolant Flowing Through Hollow Fuel Cylinder

1. Thermal-neutron flux in coolant is a minimum; poisoning by fluid and by metal through which it is conducted is less than for coolant in an annular duct. If enriched uranium is used, for which neutron diffusion length is small, coolant of high thermal cross section may be used.
2. Effective thickness of uranium metal is less than in a solid slug, for a given weight of fuel. This permits higher average flux and average metal temperature without danger from thermal effects.
3. Total heat transfer surface of slugs may be increased by providing internal cooling as supplement to external cooling. Reactor power under temperature-limited conditions can then be appreciably higher.

and p is the probability that a fast neutron will escape resonance capture in uranium during the process of slowing down from fission energy to thermal energy.

Although the numerical value of ϵ is close to unity (1.03 for a typical system), the effect of fast fission must be included in the accurate calculation of the multiplication factor of a heterogeneous natural uranium reactor (0.71 % U^{235}).

Szilard was the first to recognize the importance of ϵ. Castle, Ibser, Sacher, and Weinberg (*1*) have given the theory and method of calculation of P, the average neutron collision probability, and of ϵ for spheres, slabs, and solid uranium cylinders.

It is the purpose of this paper to describe the calculation of ϵ for the more general geometry of hollow uranium cylinders, using the theory of Guggenheim and Pryce (*2*) and the declassified fast fission cross sections for natural uranium. A solid slug is, of course, a special case of a hollow slug.

For heterogeneous natural uranium reactors, moderated by materials other than heavy water, the multiplication constant is so close to unity that the effect of the fast fission factor is important. The tabular and graphical results presented may be of use in the design of heterogeneous reactors in which the coolant flows through a central duct in the uranium slugs, rather than in an annular duct.

Fast Effect

The several fates of a fission neutron released at an arbitrary point in a slug are:

1. It may escape from the slug without suffering a collision with a uranium nucleus. The chance of this event is $1 - P$. On the average, only a few collisions with moderator nuclei are needed to bring the 2-Mev neutrons below the fission threshold for natural uranium.

2. An inelastic scattering may occur, which reduces the neutron energy below the threshold. For this effect, $\sigma_i = 2.47$ barns.*

3. The neutron may be lost by radiative capture, for which the cross section is $\sigma_c = 0.04$ barns.

4. The neutron may be scattered elastically. Since the average change in the natural logarithm of the energy is only 0.0084 in uranium, this neutron may still be classified as a fast neutron. For this effect, $\sigma_e = 1.5$ barns.

5. Fission may occur. The original neutron will be replaced by ν (= 2.55) new fast neutrons. The cross section for fast fission in natural uranium is $\sigma_f = 0.29$ barns.

Processes **2**, **3**, **4**, and **5**, for which the total cross section is $\sigma = 4.3$ barns, occur in the event of a collision of any kind. Processes **4** and **5** result in fast neutrons, which are subject to the same five possible fates as was the original fast neutron. It follows that the eventual number of fast neutrons available is the sum of all primary, secondary, and higher-order events.

Determination of the chance, P, that a collision takes place in the slug is essentially a geometric problem. The chance of collision of a neutron starting at the center of a sphere of uranium is $1 - e^{-N\sigma r}$, where N is the number of uranium nuclei per unit volume. For neutrons starting elsewhere and moving along a variety of possible paths, the value of P will be different. Of interest, however, is the average value of P. One can show, for example, that the effective P (averaged over all starting points) for a sphere of 2-cm radius is almost the same as the actual P for a neutron emerging from the center of a 4-cm sphere.

The equation for P, the average chance of collision within the metal, for a uniform thermal neutron flux is

$$P = \frac{1}{V}\int_V\int_{V'} \frac{e^{-\Sigma|\mathbf{r}-\mathbf{r}'|}\,dV\,dV'}{4\pi|\mathbf{r}-\mathbf{r}'|^2}$$

In this equation, $\mathbf{r}$ may be regarded as

Values of Collision Probability and Fast Fission Factor

r_e (cm)	r_i (cm)	α	P	$\epsilon - 1$
1.0	0.0	0.0	0.2096	0.02241
	0.2	0.2	0.2013	0.02142
	0.4	0.4	0.1743	0.01825
	0.6	0.6	0.1418	0.01458
	0.8	0.8	0.0893	0.00892
2.0	0.0	0.0	0.3543	0.04138
	0.4	0.2	0.3428	0.03975
	0.8	0.4	0.3074	0.03486
	1.2	0.6	0.2546	0.02795
	1.6	0.8	0.1665	0.01736
3.0	0.0	0.0	0.4566	0.05704
	0.6	0.2	0.4424	0.05475
	1.2	0.4	0.4044	0.04879
	1.8	0.6	0.3389	0.03920
	2.4	0.8	0.2253	0.02431
4.0	0.0	0.0	0.5368	0.07096
	0.8	0.2	0.5239	0.06842
	1.6	0.4	0.4836	0.06157
	2.4	0.6	0.4123	0.05001
	3.2	0.8	0.2844	0.03180

* The cross sections listed in this paragraph are those declassified by the Atomic Energy Commission.

the vector to the point at which the neutron begins its flight, and $\mathbf{r}'$ as the vector to the point of collision; dV and dV' are volume elements, and V is the total volume per unit length of cylinder. The expression

$$\frac{\Sigma e^{-\Sigma|\mathbf{r}-\mathbf{r}'|}}{4\pi|\mathbf{r}-\mathbf{r}'|^2}$$

is the chance that a neutron will collide in a unit volume at $\mathbf{r}'$. If the path includes part of the void within the tubular slug, the distance $|\mathbf{r}-\mathbf{r}'|$ in the exponential function must be reduced by the amount of such path.

If the thermal-neutron flux is effectively uniform in the slug, the fast fission factor can be written (*1*)*

$$\epsilon = 1 + \frac{(\nu-1)(\sigma_f/\sigma)P}{1-(1/\sigma)(\nu\sigma_f+\sigma_c)P}$$

Radiative capture in uranium is neglected in this equation. If it is included, then

$$\epsilon - 1 = \frac{(\nu-1-\sigma_c/\sigma_f)(\sigma_f/\sigma)P}{1-(1/\sigma)(\nu\sigma_f+\sigma_c)P}$$

Substituting ν and the cross sections listed above for natural uranium, one finds

$$\epsilon - 1 = \frac{0.095233P}{1-0.52081P}$$

Thus, the calculation of the fast effect depends on the evaluation of P.

Calculation

The five steps in the calculation of P and $\epsilon - 1$ are:

1. The metal shell is characterized by α, the ratio of r_i (internal radius) to r_e (external radius). A set of four values of external cylinder radii, r_e = 1, 2, 3, and 4 cm, were chosen. For each of these values of r_e, the calculation was done for internal radii corresponding to α-values of 0, 0.2, 0.4, 0.6, and 0.8.

It should be noted that $\alpha = 0$ refers to a solid cylinder, and $\alpha = 1$ is the limiting case of a shell of zero thickness (for which $\epsilon - 1$ is exactly zero).

2. The uranium density was taken as 18.7 gm/cm³, corresponding to $N = 0.04731 \times 10^{24}$ nuclei/cm³. The macroscopic total cross section for fast neutrons in uranium, $\Sigma = N\sigma$, is thus 0.20343 cm^{-1}.

3. The probability of escape, $1 - P$, may be expressed by

$$1 - P = \frac{4}{\pi(1-\alpha^2)}[F_1(\alpha,r_e) - F_2(\alpha,r_e)]$$

where

$$F_1(\alpha,r_e) = \int_0^{\sqrt{1-\alpha^2}} dy\, Ki_2(2\Sigma r_e y)\sqrt{1-y^2}$$

$$F_2(\alpha,r_e) = \int_{1-\alpha}^{\sqrt{1-\alpha^2}} dy\, Ki_2(2\Sigma r_e y) \times \sqrt{[(1+\alpha)^2-y^2][y^2-(1-\alpha)^2]}$$

are modified forms of the integrals derived by Guggenheim and Pryce (Eq. 2.12, ref. *2*). The function Ki_2 is the second-order Bessel integral (*3*) defined by the recursion relations

$$Ki_n(x) = \int_x^\infty Ki_{n-1}(t)\,dt$$

$$Ki_0(x) = K_0(x)$$

where $K_0(x)$ is the modified Bessel function, second kind, zero order.

4. Values of $Ki_2(x)$ were evaluated for steps of 0.05 in the argument, in the range 0–3.0, by Taylor's series interpolation from Bickley's table (*3*). Such an expansion is a natural one since the derivatives are lower-order Bessel integrals or Bessel functions (*4*).

5. The functions $F_1(\alpha,r_e)$ and $F_2(\alpha,r_e)$ were computed by numerical integration to an accuracy of 0.1%, and values of P were obtained from the above formula.

The table gives the calculated values of P and $\epsilon - 1$ for the 20 cylinders considered. The fast fission factor for these cylinders is plotted in the figure. Interpolation of the tabulated or graphical data may be used to obtain sufficiently accurate values of $\epsilon - 1$ for any desired hollow cylinder in the range α = 0 to 1, and r_e = 0 to 4 cm.

Application

As an illustration of the application of these results, we consider the relative sizes of ϵ for a solid, natural-uranium cylinder of radius 1.4 cm, and a hollow cylinder of the same volume of metal and with a radii ratio of α = 0.6. The internal radius is 1.05 cm, the external is 1.75 cm. From the figure we find

Solid slug: ϵ = 1.030
Hollow slug: ϵ = 1.020

The apparent loss of 1% in multiplication may be offset by the reduced poisoning and improved temperature conditions. If the 1.05-cm-radius duct were filled with a coolant such as liquid sodium, the reduction of thermal utilization, f (and k_∞), would be approximately 1%; the same amount of sodium at the surface of the 1.4-cm solid slug would change f by 2%. The difference lies in the fact that in the first case the coolant is in a flux lower than at any point in the slug whereas in the second case the reverse is true.

The temperature drop between the center and the surface of a solid slug is approximately $0.95Q/4\pi k$, where Q is the rate of heat generation per unit length and k is the metal conductivity. For a hollow slug with internal cooling, it may be shown that the temperature drop is approximately $(1/\alpha)(1-\alpha)Q/4\pi k$, or for this case, $0.67Q/4\pi k$. A power density 40% higher may be permitted in the hollow slug without exceeding any maximum metal temperature limits.

* * *

We are indebted to Dr. Alvin M. Weinberg and Dr. Robert A. Charpie of the Oak Ridge National Laboratory for their suggestions on this problem.

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* Castle *et al.* made a distinction between P and P', the probabilities of collision for primary and secondary fast neutrons.

Thermonucleonics

Last month NUCLEONICS published a letter from Dr. Ronald Richter in Argentina. At that time the editors noted that Dr. Richter had been invited to use the pages of this magazine for an up-to-date description of his thermonuclear reactors and his experiments with lithium.

Dr. Richter has since informed us that he is preparing an article for NUCLEONICS in which he will publish some details about thermonuclear reactors. He plans to submit the article within the next few months.—*Editor*

SIZE of DOSE:

Its Effect on Distribution in the Body

Tracer studies of biological distribution of isotopes cannot always be extrapolated to the dosage ranges of interest to toxicologists and therapists. Current physicochemical theory is used to explain changes in distribution with dosage

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RADIOELEMENTS have furnished for biochemists and toxicologists alike a refined tool that aids the solution of many difficult problems of metabolism. One currently popular use is the application of carrier-free isotopes for the determination of distribution and excretion of elements in the body. But an important limitation should be recognized:

Dosage may profoundly influence the pattern of distribution of an element in the body. This influence can be so great at times as to permit an entirely erroneous conclusion as to the deposition site of an element if based on results of carrier-free isotope only, and the results later applied to therapeutic or toxic doses.

It is with this aspect of radiochemistry that the present discussion is concerned. Related aspects to be discussed are the effects on elemental distribution of contaminants and disturbed physiology in the host. Interpretations of current fact and theory are presented to explain these effects.

COLLOIDAL PHAGOCYTOSABLE CATIONS

The author's attention was drawn some years ago to the phenomenon that is the basis of the present discussion. The tissues of animals exposed by inhalation to levels of beryllium sulfate differing logarithmically in concentration displayed a tissue distribution pattern for beryllium that differed strikingly from one dosage level to another (*1*); whereas animals subjected to an exposure level of 1 milligram beryllium sulfate per cubic meter of air showed no more than 1% of the beryllium content of the lung to be in the liver, comparable groups of animals exposed to 10 mg/m³ showed nearly 50 times this amount in their livers. Analysis of other tissues revealed differences which in most cases were almost as large, as shown by the table

on this page. Absolute amounts of beryllium in these tissues were not large, ranging from a few thousandths of a microgram to a few micrograms. Such findings were felt to be of great importance. If different individuals undergo exposure to different concentrations of the same material, one might expect to find a different pattern of toxic manifestations solely because of the amounts of the toxic agent in various organ sites. Again, organ-directed therapy may miss the mark through the use of improper consideration of dosage.

A physicochemical study of the solubility and of complexing capacity of beryllium in tissue fluids at different *p*H values was started by others of the group in an attempt to explain this phenomenon of dosage-regulated distribution (*2*). It was only some time later when radioberyllium became available and radiotracer studies were becoming the vogue that the distribution pattern of beryllium was again subjected to test as a function of dosage.

This second time, Be^7 was injected intravenously into two animal species—the rabbit and the rat—at two dosage levels, one as free of nonradioactive beryllium as possible, the other with inactive beryllium added to the extent of approximately a million times the dose of the tracer.

The results obtained with radiotracer technique bore out in general the results obtained in the inhalation experiments; as shown in the table, amounts of beryllium distributed to critical tissues in terms of percentage of administered dose showed differences chiefly in liver and spleen in both species but inappreciable differences in kidney and bone of four tissues measured.

These differences were more pronounced in rats than in rabbits. Similarly, consistently greater relative fecal excretion in rats resulted (2–6 times) and, conversely, less urinary excretion when carrier was given. Rabbits again showed smaller effects of dosage (*3*).

Probably the most striking example of the modifying influence of bodily constituents (and *p*H) on absorption and distribution is the recent report of Scott, Neuman and Bonner (*4*) on thorium sulfate. This water-soluble salt was rendered so absolutely insoluble upon contact with the tissues as to show (1) no measurable absorption from the gastrointestinal tract, (2) essentially no removal from the lungs, and (3) almost no transport from the site of muscle injection after 4–14 days. Although thorium forms complexes readily with certain bodily constituents such as citrate, this apparently is unimportant in its metabolism.

PROTEIN-COMPLEXING METALS

Similar effects were being noted by other workers at about this time (1950). A study of the metabolism of silver appeared by K. G. Scott and Hamilton (*5*) that gave detailed information on the relative distribution of silver at three dosage levels: carrier-free, with 0.1 mg, and with 1 mg carrier. A striking difference of as much as 100- to 300-fold increase in silver content was obtained in certain tissues from 1-mg-added carrier. This is shown in the table on this page. Increased deposition occurred in all nine tissues, and fecal excretion decreased from a major to a relatively minor proportion of the dose when 1 mg of inactive silver carrier was added. The significance of these findings to therapy was pointed out by the authors. When the dose of silver atoms per rat was increased from 10^{13} to 10^{18}, a concentration commonly used in therapy, a 10- to 100-fold increase in the concentration of silver was observed in the liver, kidney, spleen, skin, bone and muscle.

These authors (*5*) also demonstrated the profound alteration in excretory function in animals whose livers were placed under the stress of light chloroform anesthesia. Such animals were able to excrete silver at a rate only 10^{-4} normal, and silver distribution resembled that discernible when 10^4 greater amounts had been administered.

Before even more striking effects of dosage are recounted, it may be of value at this point to attempt an explanation of the above findings in the light of related work and current physicochemical theory of the biologic behavior of metals.

The alteration in amounts of beryllium deposited in the tissues of the reticuloendothelial system with altered dosage may be accounted for fairly well on the basis of actual studies on the solubility of beryllium in body fluids by Neuman and his group (*2*) and general physicochemical mechanisms proposed by Schubert (*6*). On these bases, beryllium belongs to a group of hydrolyzable metals that at the *p*H of body fluids (7.2–7.4) is incapable of existing in an ionic form except in an extremely minute concentration. For beryllium, this value is 10^{-9} *M* polymerizing as the colloidal hydroxide at values above *p*H 4.6. Evidence for aggregates of sufficient size to be trapped by the phagocytic systems is accordingly found wherever dosage exceeds this extremely minute value for beryllium. Only complexing with bodily constituents of low molecular weight permits appreciable trans-

Relative Tissue Deposition from Large and Small Doses of Metals

Values are the ratio of deposited element from large to that from small dose

Metal	*Silver*		*Beryllium*	
Animal species	*Rat (5)*	*Rat (3)*	*Rabbit (3)*	*Dog (1)*
Route of adm.	Intramuse.	Intraven.	Intraven.	Inhalation
Dosage ratio	6×10^7	10^6	10^6	7
Heart and lungs	10			7
Liver	100	16	3	45
Spleen	300	28	5	1
Kidney	8	0.85	0.72	40
Bone	10	0.73	0.96	4
Muscle	10			
Skin	30			
G.I. tract	8			
Blood	6			

port of beryllium in body fluids above this limiting value for ionic transport, and this does not appear to be the case. Colloidal hydroxide aggregates capable of being removed by the phagocytic system are the rule. Thus, the behavior of beryllium in the body may be accounted for fairly satisfactorily.

In applying the same basic theory to silver, which shows similar distribution pattern with change in dose, difficulty is immediately encountered. Silver exists in an ionic state at *p*H values of 7.5–8, which are above most physiologic ranges. According to theory, distribution should not be influenced by dosage. The fact that dosage decidedly effects even more marked changes in distribution than is seen with beryllium requires another explanation: Silver, even in the presence of chloride, complexes with protein (*7*). Such complexes indeed have been demonstrated by Scott and Hamilton between serum globulin chiefly and, to a lesser extent, with serum albumin and with red cell constituents, with a partition regulated by the proportion of each component in the blood at the time. The protein-combined silver is trapped by segments of the reticuloendothelial system and excreted by the liver; its presence in such sites as muscle and skin may presumably be accounted for by its protein affinity.

It may appear anomalous that uranium, as uranyl ion, complexes normally in the body with protein, but unlike silver is not deposited in the elements of the reticuloendothelial system. It should be pointed out, however, that uranium, unlike silver, forms also a small, readily soluble and diffusible complex with bicarbonate in proportions favoring the latter (*8*), and thus is transported without regard to the action of the reticuloendothelial system. The distribution of uranium would predictably differ from that of silver; it does, not being found in the liver, spleen or bone marrow in more than trace amounts from large doses.

FALSE CONCLUSIONS FROM RADIOTRACERS

The element yttrium provides a further example of elemental distribution. The changes in deposition from tracer amounts and from milligram amounts of stable isotopes are so striking that entirely erroneous conclusions would have been made had isotopic data been relied on exclusively.

Distribution data from the use of carrier-free Y^{91} would class yttrium as bone-seeker (*9, 10*), such as lead and strontium. But work by MacDonald *et al.* (*11*), employing an yttrium dose of 60 mg/kg intraperitoneally injected in rats on alternate days, produced no evidence to warrant such a conclusion. No evidence for accumulation of yttrium in bone was found beyond a minimal amount; on the other hand, massive accumulations occurred in the liver, spleen, lungs and kidneys. Thus, although there was evidence of good absorption from the peritoneum, as judged from the concentration in the organs comprising the reticuloendothelial system, as would be anticipated from physicochemical theory (*p*H of precipitation of Y, 6.8), no deposition occurred in bone. For the toxicologist, pharmacologist and chemotherapist these findings are of the utmost significance.

The author has noted for uranium a situation similar to that described for yttrium. On a visit to a colleague's laboratory he was shown disproportionately heavy concentrations of alpha tracks in the liver section of rats injected with tracer doses of U^{232}. From the analysis of the livers of hundreds of animals of many species exposed to varying concentrations of uranium compounds, amounts of uranium were never found in this organ in excess of trace amounts (< 0.1 μg/gm), irrespective of the degree and duration of the exposure (*8*). (The only exceptions were results with injected tetravalent uranium.) At the time the results were inexplicable; with the recognition of the discrepancy in deposition between tracer and carrier yttrium, they become more readily understandable.

Similar but less quantitative cases could be made for zirconium, chromium, and probably mercury* and a number of other elements. But the preceding examples should suffice.

Lest it be concluded that dosage effects distribution and excretion changes in all elements, it should be pointed out that Thompson and Copp (*12*) have shown that the addition of 1.25 mg inactive calcium as carrier to 5-μc doses of Ca^{45} had no appreciable influence on its metabolism.

MEASUREMENT OF ERROR FROM RADIOCONTAMINANTS

Turning to another aspect of metabolic work, that of measurement, a caution has recently been voiced by Comar in a report of the metabolism of Cu^{64}. This author pointed out the necessity for examining the need to remove radiocontaminants in metabolic work with radioisotopes (*13*). Otherwise errors can arise from two sources:

1. Animals may, by normal excretory processes, effect a selective concentration of impurities compared to the subject element.

2. If the element is short-lived, decay may add to the error, especially with impurities of appreciably longer life.

In view of the quantitative differences in body metabolism of the elements, the first factor would appear to be one of ever-present concern if the isotope contains impurities with appreciable activity.

Radiocontaminants may vary from sample to sample, as they arise from impurities of variable composition in the irradiated material used for isotope production. Purification by electrolytic procedures may offer a remedy to the difficulty.

ENZYME-REGULATED DISTRIBUTIONS

There is another type of metabolism of elements, not yet discussed, that is dosage-modified. This is the type in which the rate of physiologic activity of a specifically functioning system plays the determining role. Examples are the thyroxin-forming systems of the thyroid cells involving iodine incorporation into a complex organic residue, and the systems responsible for incorporating iron into hemoglobin and presumably other iron-containing porphyrins.†

These systems represent an entirely

* Data comparable as to route of administration, species, time of sampling, etc., at different doses are not available on most elements, but roughly comparable data indicate dosage-dependent distributions for these three elements at least.

† Undoubtedly the same type of physiologically regulated processes exist in the metabolism of other trace metals in the body such as Co, Zn, Cu, etc., but their absolute quantity is so small that it does not influence the over-all picture at therapeutic levels.

different type in that the governing factor is the rate of incorporation of the element in a system. The rate is in general slower than the more directly chemically mediated metabolic reactions such as that discussed for silver. In physiologically dominated metabolisms, increasing the dosage results in a percentage-wise decrease of deposition in respect to the dose, not in an increased deposition in the system. In the case of iodine, whereas a 0.001-μg dose resulted in 65% uptake by the thyroid of rats, 0.03 μg gave only 7% and 0.5 mg showed only 2% uptake of the dose administered (*14*). Similar patterns were found by these authors for human thyroid and by other workers (*15*) with different species.

Iron, perhaps even more than iodine, represents an unusual case of elemental metabolism that is governed by a sequence of physiologic events, rather than more directly by precipitation and phagocytic phenomena. When the dosage is modified, as in the case of iodine, in the direction of decreasing percentage-wise absorption with increasing dosage by ingestion, the limiting factor appears to be combination of the iron with apoferritin phosphate, an enzyme-catalyzed reaction in the mucosal cells of the upper gastrointestinal tract. Iron is discharged from this site to restore diminishing dosage depots.

Once the cells are replete with ferritin, only minimal iron absorption occurs until the iron is released into the circulation; thus, through a complicated series of rate-regulated events, the dosage-distribution pattern of iron is determined following ingestion. Although the mode of distribution of iron by parenteral routes differs markedly, it will be neglected here because of relative lack of clinical importance at the present time. Few parenteral agents are available.

Iron is most peculiar also, differing from all other elements, in that the rate of excretion of the amount absorbed is not affected by dosage; in fact, most of the absorbed iron is not excreted at all. The excess of large doses is stored in the spleen, liver and other organs.

EFFECT OF PHYSIOLOGIC STRESS

Some such rate-dominated processes undoubtedly determine the distribution differences of elements in disease and in health. It was shown more than a decade ago by Hamilton (*15*) that different pathologic states of the thyroid exerted a marked influence on the uptake of iodine, and that increasingly greater amounts of iodine administered in the dosage of 0.1 μg of carrier-containing iodine were deposited in the following order in the different thyroid states: hyperthyroid without goiter (3%), normal thyroid (15%), nontoxic goiter (22%), and toxic goiter (55%). The pattern of tissue distribution of cobalt was also modified to some extent by the leukemic process in mice injected with Co^{60} (*16*). When iron stores are depleted, as in certain anemias, iron absorption increases 10- to 20-fold.

SUMMARY

In summary, often substantial quantitative, and at times qualitative, differences in distribution and excretion of an element in the body follow upon the administration of different dosage levels. With certain elements these differences can be so great as to result in erroneous conclusions as to the tendency of an element to accumulate in certain organ sites. It is unfortunate that the refinements offered by the carrier-free radioelement technique cannot serve at once the radiochemist, the toxicologist and the chemotherapist.

Current physicochemical theory and experimental results thus far available have been used here to furnish a reasonable explanation as to why certain of these differences in distribution with dose occur. The review has attempted to develop the fact that there are at least three distinct mechanisms that regulate the distribution of an element in the body.

The most general of these appears to be the mechanism of phagocytosis by the reticuloendothelial system components for those elements that exist as colloidal hydroxide aggregates at physiologic *p*H values and whose distribution increases in the system chiefly upon increase in dosage. Beryllium typifies this group. A similar mechanism is entailed with elements such as silver that complex with colloidal moieties such as proteins and later accumulate in the reticuloendothelial system and skin.

A different mechanism governs those cations that exist as such at all bodily *p*H values. Examples are sodium and magnesium. These elements do not accumulate in the reticuloendothelial organs. Presumably those elements that complex firmly with small organic constituents of the circulation behave from a distribution standpoint like these basic, nonhydrolyzable cations, but little factual material is available on this point.

A third mechanism involves what has been herein called physiologically-regulated metabolisms that are rate-governed by a rather complex series of enzymic reactions in contrast to more directly chemically-mediated reactions. Under normal conditions this third mechanism is restricted, as far as is known, to relatively few elements, such as iron and iodine, but in disease and in conditions of stress it is undoubtedly this type of mechanism that modifies the normal distribution of an element. Instances of this have been briefly noted in a preceding section of this article.

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Effect of High Beta Backgrounds on Precision Alpha Counting

Studies on a Simpson proportional alpha counter indicate that beta backgrounds of 3×10^7 dpm reduce the observed alpha counting rate by 0.5%. This reduction increases to 2% for backgrounds of 4×10^8 dpm

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THE PROPORTIONAL ALPHA COUNTER designed by Simpson (*1*) has found extensive application in the precise determination of alpha activities. Of primary importance among the many characteristics that make this instrument an extremely useful analytical tool is its ability to count alpha activity in the presence of high-level beta activity. This report is an evaluation of the effects of intense, sub-tolerance β-activities on α-counting rates that are observed with this instrument.

The presence of greater than approximately 3×10^7 dpm of beta activity on a source whose alpha activity is to be determined results in a reduction in the alpha counting rate as measured with the Simpson proportional alpha counter. At the normal operating voltage for this instrument, approximately 200 volts below the beta threshold for a given beta intensity, the reduction in alpha counting rate varies from approximately 0.5% with 3×10^7 dpm of beta activity present to about 2% for 4×10^8 dpm of beta activity. The magnitude of the reduction is a function of operating voltage, beta intensity, beta energy, alpha pulse-amplitude distribution, input amplitude threshold, and individual instrument circuit characteristics.

Proportional Counter Theory

The ion detector of the instrument is a proportional chamber through which methane flows at atmospheric pressure. The collecting electrode is a 2-mil diameter tungsten wire held at a positive potential of approximately 2,000 volts with respect to the chamber walls, which act as the cathode.

The proportional counting region is that section of the pulse-height-vs-voltage curve which falls between the saturated ion-chamber region and the region of limited proportionality. In the proportional region, the pulse height observed when an ionizing event occurs in the chamber is proportional to the initial number of ion pairs formed by the event.

Methane is used for the chamber atmosphere because ionization of this gas by the primary ionizing event does not lead to the emission of photons which, in turn, would produce photoelectrons and destroy the proportionality of the counter response (*2*).

A second important advantage realized through the use of this polyatomic gas is that it displays a stable amplification factor with respect to voltage (*3*). The gas amplification factor at a specified voltage may be defined as the ratio of the number of electrons collected at that voltage to the number collected at a voltage in the saturated ion-chamber region, where no gas amplification occurs; in other words it is the ratio of the charge collected at the anode to the charge produced by the primary ionizing event (*3*).

The specific ionization (*4*) of an alpha particle is much greater than that of a beta particle. Because of this and the proportional response of the counter it is possible, by proper selection of the input amplitude threshold, to count alpha activity in the presence of beta activity without interference by the latter. The input amplitude threshold defines the bias set into the circuit to discriminate against pulses with amplitudes less than the selected value.

Figure 1 shows a typical curve of counting rate vs voltage for this instrument. Ideally, the instrument is operated at a voltage corresponding to the center of the alpha-plateau region to assure maximum stability of counting rate with respect to voltage fluctuations. Because of increased gas amplification at higher voltages, beta activity, if present, is detected by this instrument in the way shown by the three beta curves of Fig. 1 corresponding to three different values of beta activity. It is evident, then, that the presence of beta activity effectively reduces the length of the alpha plateau. Because of this it is necessary to specify a beta threshold and a beta tolerance for this instrument.

The beta threshold is defined as that voltage which, for a given beta intensity, permits beta-beta pile-up pulses to attain an amplitude equal to the amplitude of the smallest detectable alpha pulse. At a specified operating

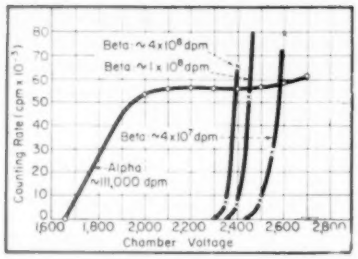

FIG. 1. Alpha and beta counting-rate curves for Simpson proportional counter

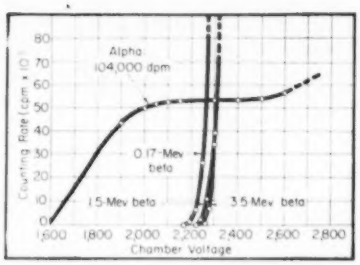

FIG. 2. Simpson counter thresholds for 5×10^5 dpm of beta activity

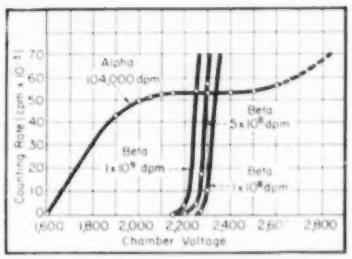

FIG. 3. Simpson counter tolerance for 0.17-Mev betas

voltage, the beta tolerance is that beta intensity which permits beta-beta pile-up pulses to attain an amplitude just less than the amplitude of the smallest detectable alpha pulse. The beta threshold and beta tolerance are functions of beta intensity and operating voltage and also of beta energy.

Since the specific ionization of a beta particle varies inversely as its velocity, the pulse produced by a low-energy particle for a given path length in the chamber is greater than that produced by a higher-energy particle. For this reason, the beta threshold for a given beta intensity is lower for lower-energy betas. It follows from this that the beta tolerance at a specified voltage is also lower for lower-energy beta activities. Experimental verification of the dependence of beta threshold and beta tolerance on voltage, intensity, and energy is shown in Figs. 2 and 3.

Experimental Methods

The paired half-disk technique, commonly used for the determination of coincidence losses (*5*), was employed in this study. Platinum disks 22 mm in diameter and 5 mils thick were cut across a diameter. Alpha activity was deposited on one half-disk, and known intensities of beta activity were deposited on other half-disks. The counting rate of the alpha half-disk was precisely determined in the presence of a blank half-disk. The blank half-disk, on which no activity was present, was used to eliminate any changes in counting geometry. The observed counting rate of the alpha half-disk was then redetermined in the presence of beta half-disks at various operating voltages along the alpha plateau and with varying, known intensities of beta activity present.

The study can conveniently be broken down into two distinct phases. In the first phase, the source of beta activity used in the preparation of the beta half-disks was a solution of mixed fission products containing alpha, beta, and gamma activities. In the second phase of the study, the beta half-disks were prepared with isolated nuclear species emitting only beta activity. The beta emitters used for the second phase were S^{35}, Y^{91}, and Ru^{106}, with maximum beta energies of 0.17, 1.5, and 3.5 Mev, respectively.

The half-disks for the first phase of the study were prepared as follows:

Half-disk 1. Alpha activity was deposited by evaporation of a standard plutonium solution.

Half-disk 2. Mixed fission products were deposited by evaporation. Sample aliquots were chosen to yield a series of disks with the various beta intensities to be investigated.

Half-disk 3. This was a blank half-disk with no activity deposited on it.

The alpha counting rates of disk combinations 1 and 3, 1 and 2, and 2 and 3 were determined at various operating voltages on the alpha plateau and with various beta intensities present on disk 2. The presence of alpha activity on the beta half-disk, of course, necessitated the precise determination of the counting rate of disk combination 2 and 3.

In the second phase of the study, the half-disks were again prepared as outlined above except that half-disks 2 were prepared using the three separated isotopes, which decay by the emission of beta particles. Therefore, no alpha activity was present on the beta half-disks for this phase of the study, and determination of the counting rate of combination 2 and 3 was not necessary.

The beta activities were determined by counting suitable aliquots on a standard beta-gamma counter which uses an end-window G-M tube, and on the Tracerlab SC-16 windowless flow counter. The counting rates obtained with the G-M tube were converted to disintegrations per minute by application of the backscatter correction and the relation between counting efficiency and maximum beta energy (*6*).

Backscatter correction was also applied to the counting rates obtained with the flow counter, and a 50% counting efficiency was assumed for this instrument. The activity values obtained with the two instruments agreed within a factor of two for the mixed beta-gamma sources, and within 30% for the individual beta emitters.

Experimental Results

First phase. A series of counting determinations at various voltages, using beta half-disks with activities of 3×10^7, 1×10^8, and 4×10^8 dpm, showed that the presence of these sub-tolerance beta activities caused a reduction in the observed counting rate of the alpha half-disk. The magnitudes of these reductions are summarized in Fig. 4 as functions of operating voltage and beta intensity. The values of per cent change in alpha counting rate were calculated by:

$$\text{Per cent change} = \frac{C_{1+2} - (C_1 + C_2)}{C_1 + C_2}$$

where C is the counting rate, and the subscripts refer to the number of the particular disk.

Since alpha activity was also present on the beta half-disk in this phase of the study, the above calculation is biased by the fact that the observed alpha counting rate of the beta half-disk is low because of the presence of the beta activity. This factor is neglected in the values in Fig. 4.

All of the observed differences in counting rate were analyzed by use of the Student-Fisher *t*-statistic to show that the differences were real and

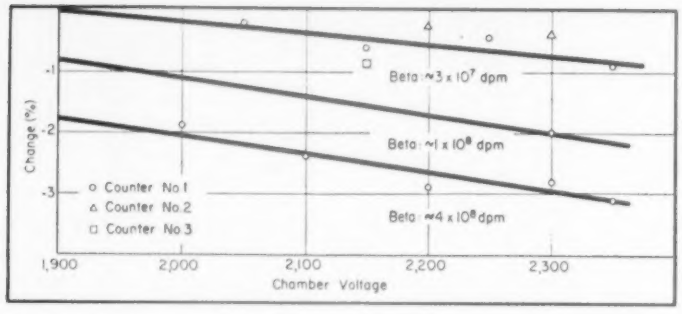

FIG. 4. Change in observed alpha counting rate in presence of three different beta backgrounds for the Simpson counter

Change in Alpha Counting Rate in Presence of 5×10^8 dpm of Betas

Maximum beta energy (Mev)	*Change in alpha counting rate (%)*			*Average change (%)*
0.17	−0.10	−0.15	−0.29	−0.18
1.5	−0.08	−0.17	−0.05	−0.10
3.5	−1.3	−0.85	−0.8	−0.98

not merely due to random counting fluctuations.

Second phase. A series of counting determinations were made with three beta half-disks on which had been deposited 5×10^8 dpm of beta activity with maximum energies of 0.17, 1.5, and 3.5 Mev, respectively. The counting rate of the alpha half-disk alone (disk 1) was 52,265 ± 35 cpm at the 99% level of reliability.

The per cent change in observed counting rate of the alpha half-disk when in the presence of the beta half-disk was calculated by:

Per cent change = $(C_{1+2} - C_1)/C_1$

The results of this phase of the study are summarized in the table. Each of the three values of percentage change at the three different maximum beta energies were obtained through eight replications of 5-min counts. Four of the 5-min counts were on disk combination 1 and 2 and four were on disk combination 1 and 3.

The data are too limited to warrant statistical analysis. The fact that each value of per cent change is negative is sufficient to show that the observed effect is not due to random counting fluctuations. The probability of obtaining this result by chance is only 0.002.

Mechanism

A study of the input amplitude threshold of this circuit was undertaken in an attempt to establish the mechanism by which the presence of these sub-tolerance beta activities caused the observed reduction in alpha counting rate. By use of a pulse generator it was found that the presence of the intense beta activities produced a fluctuation in the normal input threshold of the instrument.

Figures 5 and 6 show this observed fluctuation in input threshold for beta activities of 3×10^7 and 4×10^8 dpm, at various operating voltages along the alpha plateau. The curves indicated as "normal threshold" are obtained from the pulse generator with no activity present in the chamber. The remaining three curves in each of the figures are obtained with the indicated sub-tolerance beta activities present in the chamber at the operating potential shown on the curves.

The sources used in this part of the work were those used in the first phase discussed above, with the addition of a single layer of cellulose tape over the disks to absorb the alpha activity. The data of Figs. 5 and 6 are not intended for quantitative evaluation of this effect, and the curves obtained with beta activity in the chamber should probably show greater symmetry to the normal curve than is indicated.

Considerations of these data showing the effect of intense, sub-tolerance beta activity on the input threshold of the instrument lead to the postulate that the observed fluctuation is due to a disturbance in the base line or reference potential from which the pulse amplitudes are measured. Oscillographic observation of the amplifier output showed this disturbance of amplifier base line with beta activity present in the chamber.

It was then predicted that, if the distribution of alpha pulse amplitudes for this chamber were of a required form, the result of this disturbance would be a net reduction in detectable alpha pulses. The form required for this distribution would be one in which the number of alpha pulses with amplitudes just exceeding the input threshold is greater than the number with amplitudes just less than this value.

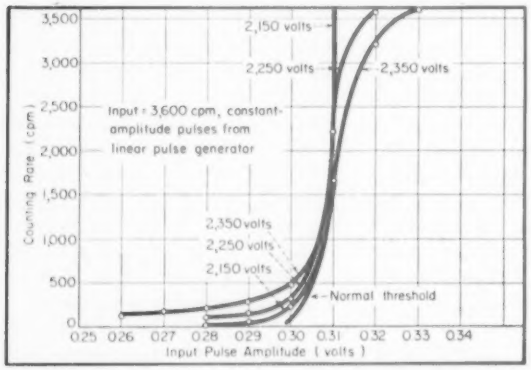

FIG. 5. Fluctuation in input threshold for 3×10^7 dpm of beta activity at various voltages along the alpha plateau

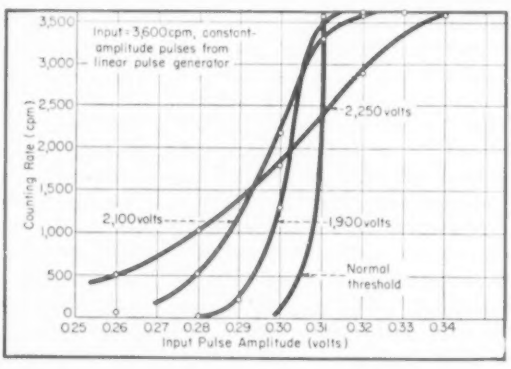

FIG. 6. Fluctuation in input threshold for 4×10^8 dpm of beta activity at various voltages along the alpha plateau

A determination of the alpha pulse amplitude distribution was then made using a single-channel differential pulse-height analyzer, and the predicted form was found to exist. Figure 7 shows the distribution found with the Simpson counter and also that found with another counter. Each point on this curve represents the observed counting rate for pulses with amplitudes that fall within 2-volt increments of bias.

Because the base line of the amplifier fluctuates when an intense, sub-tolerance beta activity is introduced into the chamber, the distribution of pulse amplitudes in Fig. 7 will oscillate along the horizontal axis. If this oscillation is of equal magnitude in each direction across the normal input threshold value, the result will be a net loss of detectable alpha pulses; a greater number of pulses are brought below the threshold value as the distribution shifts downward—to the left—than are brought above the threshold as the distribution moves upward—to the right.

The input threshold, shown in Fig. 7, was determined by obtaining integral counting rates at successively lower values of pulse-analyzer bias voltage. The bias voltage at which the integral counting rate through the pulse analyzer equals the observed counting rate on the Simpson scaler defines the input threshold; all pulses with amplitudes greater than this value of bias are detected and recorded by the Simpson unit.

The distribution of alpha pulse amplitudes was determined for another proportional alpha chamber. The design of this chamber differed only slightly from that of the Simpson chamber. The distribution of alpha pulse amplitudes for the second chamber is shown in Fig. 7. If the proposed mechanism of the observed beta effect is valid, reference to Fig. 7 would indicate that the pulse-amplitude distribution for the second chamber would yield a smaller reduction in observed alpha counting rate, in the presence of a given beta intensity, than was exhibited by the Simpson chamber.

Experimental determination of the effect of a sub-tolerance beta activity of 4×10^5 dpm on these two chambers, using the same alpha, beta, and blank half-disks as well as the same amplifier, showed a 3% reduction for the Simpson chamber, and 1% for the other.

These results indicate that the proposed mechanism of the beta background effect is confirmed. However, the relation of the input threshold to the pulse-amplitude distribution has not been firmly established. Preliminary studies indicate that the input threshold not only fluctuates about an average value but varies from this average as a function of pulse amplitude or other, as yet unknown, factors.

Discussion

Before this study was undertaken, it had been predicted that an increase in alpha counting rate would be observed when this rate was determined in the presence of intense, sub-tolerance beta activity. This prediction was based on consideration of the probability for coincident occurrence of small alpha and beta pulses. The coincident occurrence of two such pulses, each of which would normally possess amplitudes below the input threshold, would result in an apparent alpha pulse possessing a magnitude sufficiently large to trigger the input circuit. Because of the random nature of these ionizing events, alpha-beta pile-up pulses occur, but the resulting effect is masked by the greater effect reported here. Theoretical considerations, using the observed distribution of alpha and beta pulse amplitudes for this chamber, and the resolving time of 1×10^{-7} min found for alpha pulses, led to an estimate of $\sim$0.1% for the occurrence of alpha-beta pile-up pulses of sufficient amplitude to trigger the input circuit when 5×10^3 dpm of beta and 5×10^4 dpm of alpha activity are present in the chamber.

Throughout the study, a decrease in the reproducibility of the alpha counting rate was observed when intense beta activity was also present in the chamber. Values of χ^2, a statistical quantity that measures the extent to which a series of measurements cluster about their expected value, were calculated for replicate determinations when only the alpha half-disk was present in the chamber. These values were consistently lower than those obtained for a similar series of counting determinations with beta activity also present. This factor makes exact evaluation of the magnitude of the observed effect very difficult.

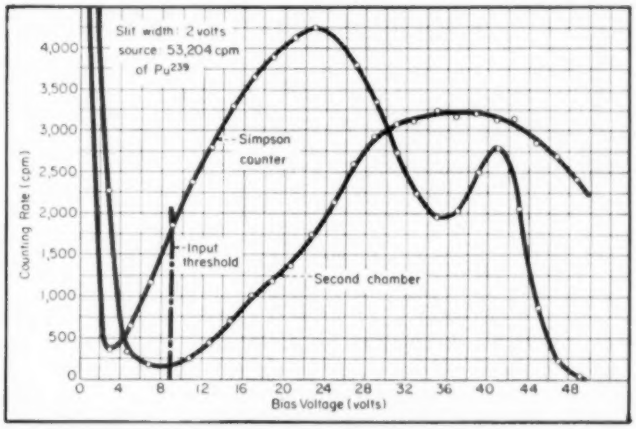

FIG. 7. Alpha pulse amplitude distribution for two chambers

To eliminate or minimize this reduction in alpha counting rate caused by the presence of intense, sub-tolerance beta activities, at least three approaches are at once evident. First, the intensity of beta activity introduced into the chamber can be reduced, when possible for a given analysis, by reduction of sample aliquots or by separation techniques. Second, excellent possibilities are evident in chamber design modifications to yield a distribution of alpha pulse amplitudes with zero slope in the region of the input threshold. Finally, modification of the input circuit to obtain increased pulse resolution offers a possibility.

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Market for "Package" Nuclear Power

High-cost power areas may provide the first testing ground for power reactors. This analysis of domestic and military power costs shows a potential market at overseas military installations

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THE HIGH COST of development in the field of atomic power has stimulated a number of proposals for minimizing private risk. Most of the proposals require some degree of government financial participation, ranging from outright Federal construction to indirect subsidy through a guaranteed market for fissionable byproducts of the reactors.

The "package plant" proposal described by Alvin Weinberg (NU, Nov. '52, p. 31) is particularly interesting because it attempts to eliminate the need for government participation by removing the barrier set against private development by excessive cost and high risk. The suggestion calls for initial development of the atomic power industry through construction of small and relatively inexpensive "package" reactors. The cost of a small reactor producing about 5,000 kw of electricity would be low enough to allow private industry to invest. The Federal government would be required to provide access to necessary information and amend the Atomic Energy Act—actions that are necessary for any private development in the field.

The cost of package reactors would still be inordinately high per kilowatt of electrical capacity compared to conventional generating plants. Weinberg and others have set the figure at about $500 per kw of capacity. However, the total cost of a reactor of 5,000 kw—about $2,500,000—would be well within the reach of a large number of electrical utilities and other companies interested in the production of electricity. If a working reactor can be built at this cost level there should be no lack of investors willing to make an investment that could be expected to repay itself many times over in experience and technological knowledge. In fact, it seems fair to expect the first

TABLE 1—Production Costs of Diesel Station of 7,500 kw

Fuel (¢/gal)	*10*	*15*	*20*
	(mills per kwh)		
Capital, at 15%	4.1	4.1	4.1
Maintenance, supplies, etc.	3.0	3.0	3.0
Fuel	7.1	10.7	14.3
Total	14.2	17.8	21.4

TABLE 2—Cost of Electric Power to U. S. Armed Forces Overseas*

Area	*Supply service*	*Type plant*	*Average energy cost† (cents/kwh)*
Alaska	Army	diesel	3.0
	Air Force	diesel; steam	3.5
Greenland	Air Force	diesel	2.0 to 6.0
Guam	Navy	diesel	2.5
Europe	Army	thermal; hydro	1.5 to 4.0
Okinawa	Army	diesel	1.8
Saudi Arabia	Air Force	diesel	1.4
Philippine Islands	Air Force	diesel	1.3

* Source: Department of Defense. † Excluding capital costs.

reactors to earn less than the normal 6% return on the grounds that experience and probable discoveries during construction and operation constitute a potentially much greater return.

Success of the proposal, however, depends on the discovery of locations at which the necessarily high-cost electricity produced by expensive reactors could be sold at a profit—or at least not at a loss. NUCLEONICS, at the suggestion of Weinberg, is investigating possible locations. This article deals with opportunities in the United States and areas under its jurisdiction; a future article will deal with foreign markets.

The Domestic Market

Weinberg estimates that power could be produced in a 5,000-kw package reactor for between 2½ and 4 cents per kilowatt-hour. Other estimates fall in or near the same range, tending toward the higher figure. At these prices, nuclear power cannot compete at any of the current power plant sites in the United States. The suggested cost of power is several times as great as the usual generating cost in the United States; and the few instances in which power produced in the United States costs more can be explained on grounds which allow no opening for atomic power. In general, higher cost plants now operating are very small or ancient, and modern plants of 5,000 kw or more in the same locations could produce power for less than the cost of package nuclear power.

Any potential markets, therefore, are new ones, remote from the locations of present power plants. Furthermore, they must be relatively remote from potential hydroelectric power and from deposits of coal. Hydroelectric power and power from coal-burning steam plants can almost always be delivered at a cost of less than 2.5 cents per kwh unless either the coal or the power must be transported over long distances. There are very few places in the United States today in which generating costs are greater than even 1.5 cents per kwh.

Under these circumstances, the cost of electricity from diesel plants becomes the standard for profitable operation of an atomic package plant, since diesels can be located anywhere that an atomic plant can be located. Diesel plants are themselves high cost by conventional standards, but the possibilities for atomic generation at the costs estimated depend on the location of demand being so remote that costs of transporting fuel oil more than overbalance the capital cost advantage of the diesel plant.

In addition to being remote, any possible market must demand a firm flow of electricity. An atomic plant must be operated at the highest possible load factor in order to minimize the burden of capital cost on each unit of output. At capital costs of $500 per kw of capacity, for instance, and an annual capital charge of 15%, a drop from 100% plant use to 50% would add about 8.6 mills to the cost of each kwh of electricity generated. Plant load factor is not nearly so important for conventional facilities because the capital cost is so much lower. At capital costs of $200, which is high for conventional plants, the difference in capital cost per kwh between 100% and 50% operation would be only 3.4 mills.

The requirement of firm demand for power severely restricts the number of locations which can be considered, because it removes from consideration markets with the usual marked seasonal patterns of demand. Pumping stations in remote mines, perhaps combined with some residential or industrial demand, have been suggested as possibilities.

With these considerations in mind, it does not seem likely that there is a potential domestic market for electricity from package plants at the costs estimated by Weinberg. It is likely that the cost of generating electricity from a diesel plant of 5,000 kw or more would not exceed 2 cents per kwh anywhere in the United States, and virtually certain that it would not get into the more-than-2½ cent range considered possible for package atomic plants.

Table 1 is based on reasonable maximum costs for a diesel plant located in a remote section of the United States. The plant would consist of three 2,500-kw diesel units costing $160 per kilowatt and would be designed to operate at 67% of capacity. The requirement of high utilization, which is necessary for atomic package generation, also benefits the diesel plant and accounts for the relatively low capital charges.

It is unlikely that diesel fuel in the quantities required would cost much if any more than 15 cents per gallon in the United States. Yet apparently diesel generation would be cheaper than atomic generation even at the unlikely fuel cost of 20 cents a gallon or even 25 cents.

Exploitation of the domestic market thus is dependent either on government subsidization or on technological improvements, especially to lower capital costs. It seems likely that these improvements will come in the development of larger reactors rather than in refinement of designs for small reactors which must inevitably be more expensive.

The Military Market

There remains the possibility that there may be a military market in which the high cost of package reactors can be justified. Remote air and naval bases consume amounts of power in the range that could be served with package reactors.

High-cost atomic power might be justified at remote military installations on logistic grounds. Use of atomic power would save shipping in wartime, since little fuel would have to be shipped. It would also eliminate the possibility that shipments might be intercepted, which could be a real danger at distant bases in the Pacific or in Greenland.

In addition, use of atomic power at some remote bases can be justified solely on grounds of comparative costs. Power now produced at these bases is excessively expensive. The figures in Table 2, provided by the Nuclear Power Division of the Army Corps of Engineers, include only fuel, maintenance supplies and services, with no allowance for capital costs. Yet many of them fall in the 2½–4 cent category.

While installation of more modern equipment (now under way at some of these areas) would lower costs materially, it is clear that atomic generation would be justified on the grounds of cost alone at a substantial number of overseas American installations. The fact that military reactors need not earn profit or pay taxes reduces the capital cost disadvantage at which nuclear power reactors must operate. The military market has an additional advantage in that its development would not require changes in security rules which, while they will certainly be made eventually, may be slow in coming. —END

Scintillation Unit for Drill-Hole

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SAMPLE DRILLING operations are used extensively in the exploration for uranium bearing ores. Core drilling provides a geological sample, but it is expensive and in many cases the core is lost in the friable mineralized region of greatest interest. Geiger-counter probes have been used to indicate position and grade of ore at levels where no core has been recovered. But these probes have several limitations that, as shown in the table at left, can be overcome with a scintillation-counter unit.

Because of its distinct physical advantages, a scintillation type probe and associated surface circuitry was designed and built for interchangeable use in existing field logging equipment of the AEC Raw Materials Division. Its superior performance has been supplemented by new mechanical equipment. The complete unit is shown in Fig. 1.

Four major requirements had to be fulfilled in this design:

1. The scintillation probe was to have a maximum outside diameter of 2 in.

2. Electronic circuitry in the probe was to be fed through a single coaxial cable from a power source of 60 volts rms at 400 cycles so that it would operate the logging equipment interchangeably with existing G-M equipment.

3. The cable was to be 1,000 ft long. Besides furnishing power to the probe, it was to transmit probe signals back to the surface, and, of course, to support the probe during its descent and withdrawal from the drill hole.

4. Surface equipment was to be operated from a standard 110-volt 60-cycle source.

Figures 2 and 3 show the electronic circuits developed to meet these requirements. These circuits and associated mechanical equipment are described here.

Probe

The probe housing contains five major parts; the detector, amplifier, B-voltage, high-voltage, and filament supplies.

Detector. This unit is shown in Fig. 4. A thallium-activated sodium iodide crystal 1⅛ in. in diameter and 1½ in. long is hermetically sealed into an aluminum housing having a Vycor glass window.* Canning of the crystal is necessary because sodium iodide is extremely hygroscopic; moisture reacting with it forms an opaque coating that greatly affects light output.

The sealed crystal is optically coupled to the Vycor window by interposing a layer of silicone oil that has an index of refraction close to that of the crystal and Vycor glass. This minimizes loss of light from the crystal due to reflections at the interfaces.

The crystal assembly is optically coupled to the face of a photomultiplier tube, again using silicone oil. The tube used, an RCA developmental type C-7151A,† has a transmission-type photocathode that allows good optical coupling between the crystal and the photocathode. Optical coupling was improved when the tube was modified according to NYOO specifications to have a flat photocathode.‡

The maximum diameter of this tube is 1.527 in. It is the smallest tube presently available with this type of cathode construction.

This tube requires from 600 to 1,000 volts d-c divided among its dynodes. The actual voltage applied is selected so that the particular tube used delivers about 0.2 volts per Mev to the voltage amplifier. A resistance dividing network is built into a brass cylindrical housing that also supports the tube.

Since photomultiplier tubes are appreciably affected by stray magnetic fields, a magnetic shield of novel construction was designed to fit over the tube in the probe. A mu-metal strip 0.005 in. thick and 4 in. wide is wound around a cylindrical mandrel of the same diameter as the photomultiplier. A sufficient number of turns are used to build the shield up to a thickness of 0.050 in. The rolled assembly is spot welded together and then hydrogen annealed. This produces a shield with a uniform wall thickness, eliminating the double thickness of the conventional lap weld.

Amplifier. Pulses from the photomultiplier are amplified and then fed to the low-impedance cable. It was decided that the cable could best be driven by a power pentode, using a transformer for impedance matching. The transformer was specially designed for this application. It serves to match impedances electrically and is so designed that its response at 400 cycles is extremely poor. The secondary of this transformer is coupled to the line in series with a 0.1 μf capacitor. This serves as a frequency dividing network, so that 90% of the 400-cycle line voltage to power the probe appears across the capacitor, yet in the pulse frequency range there is little drop through the capacitor.

For the power pentode stage, the 6AK6 was selected because of its filament drain and other adequate electrical characteristics. The power developed by this stage is sufficient to insure meeting the minimum detectable energy level of 30 kev set by the surface unit. To conserve standby power, the stage is biased near cut-off, requiring positive pulses at the grid. The sensi-

* Harshaw Chemical Co.
† Now available as RCA type 6199 and Dumont type K1185.
‡ RCA Lancaster C-7151A.

FIG. 1. Complete scintillation logging unit mounted in Jeep

tivity at this point in the circuit is 9 volts/Mev.

Since feedback is desired to secure gain stability in the voltage amplifier circuit, a two-stage amplifier is used. A consideration of pulse polarities indicated the need of positive pulses from the photomultiplier tube. These can be obtained from the last dynode. The necessary voltage gain of 45 is easily obtained with a 12AT7 dual triode.

B-voltage supply. Full-wave rectification using a 400-cycle center-tapped-secondary transformer manufactured to specifications is used to supply B+ voltage for the preamplifier. The rectifier is a 12AL5 diode tube, chosen for its small physical size and low filament drain. Although this tube is normally used approximately 20% above its rated maximum inverse value, life tests were conducted at double the rated value without any failure occurring.

An *RC* filter is used to smooth out the rectified voltage. Stabilization is not required. Under full load conditions, 210 volts at 8 ma with a 0.01% ripple content is obtained.

High-voltage supply. This circuit utilizes a full-wave doubling system fed from a transformer designed to specifications. Two selenium rectifiers§ about ¼ in. in diameter and 2½ in. long are used because of their small physical size and because, unlike rectifier tubes, no filament power is required.

Since the amplitude of the photomultiplier output pulse is greatly dependent on dynode voltage, a corona-type regulator¶ is used, regulating at 1,000 volts. This tube is small and gives good regulation with currents of the order of 50–100 μa. The design of this power supply is such that the high voltage will remain essentially

§ Bradley type SESL55H.
¶ Raytheon type QF771.

"The Colorado Plateau area in the western United States has evolved into one of the largest sources of uranium in the world. Nearly 200 uranium mines are now in operation in the Plateau sandstones, producing from bodies of secondary ore that are sporadic in distribution and irregular in configuration.

"Over a million feet of exploratory drilling is being undertaken each year in an effort to delineate these ore bodies. . . . This scintillation logging equipment should result in tremendous time saving, so important in our production efforts."

R. S. Foote, *Chief, Geophysical Section, Raw Materials, U. S. AEC*

COMPARISON of new scintillation unit with older Geiger units

	GEIGER LOGGING	SCINTILLATION LOGGING
RANGE	Several G-M probes needed to cover 1,000-to-1 range of gamma intensities encountered.	Single detecting unit will cover entire range of activities encountered.
RESOLUTION	Length of sensitive volume of G-M tubes decreases space resolution, and uranium ores are frequently found in extremely narrow strata.	NaI crystal has high absorption coefficient, is thus efficient detector of gamma rays. Small crystal can be used, allowing increased space resolution.
LOGGING SPEED	Speeds of 1-6 ft/min needed to obtain good statistical precision. Low counting rates required due to low efficiency, long recovery times (150-200 μsec) of counter.	Speed increased by factor of five: high counting rates possible since pulse duration is 1-2 μsec and scintillation counter exhibits no direct deadtime.
ORE IDENTIFICATION	Core drilling for ore specimens necessary since G-M tube gives same size pulse regardless of energy of gamma ray. Core is sometimes lost.	Possible to obtain gamma spectra during logging since scintillation intensity is proportional to absorbed energy of incident gamma ray. Lab tests indicate ore can be identified.
MECHANICAL EQUIPMENT	Requires 15-30 minutes to set up equipment with conventional apparatus.	Set-up time cut to 5 minutes by mechanical design and arrangement.

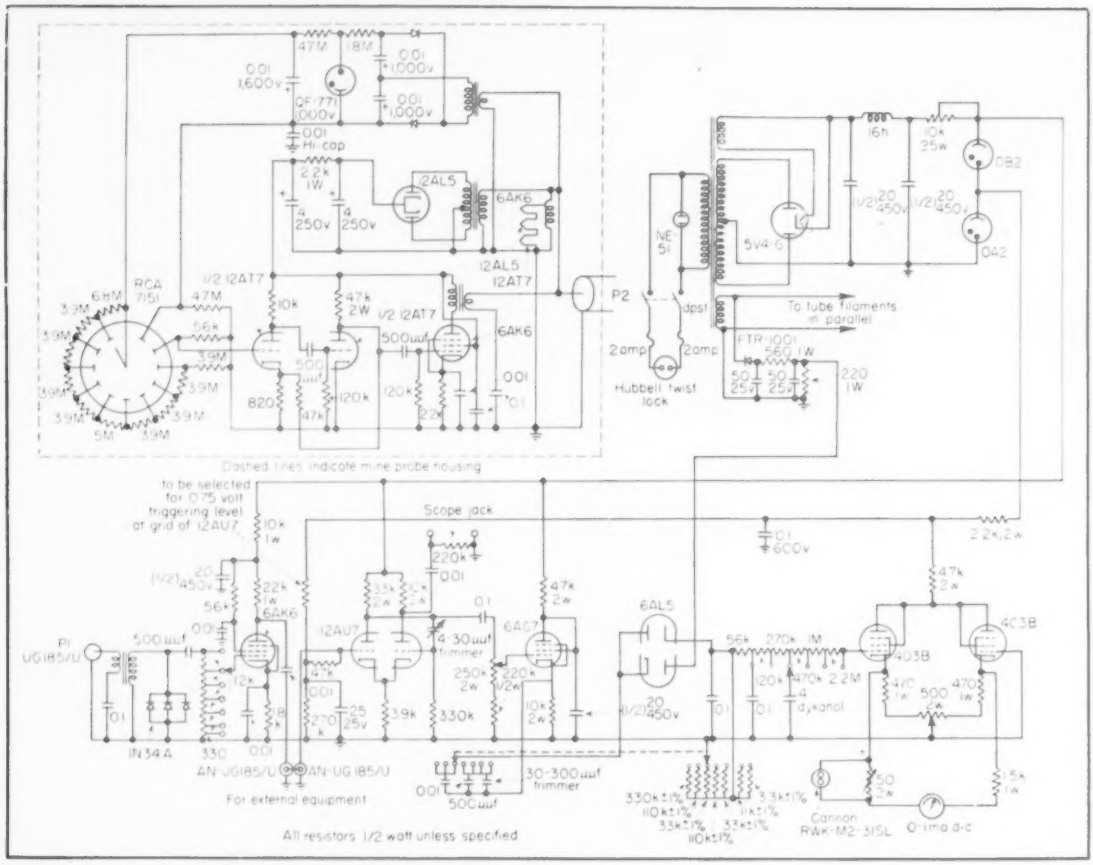

FIG. 2. Circuits of scintillation probe and logging unit

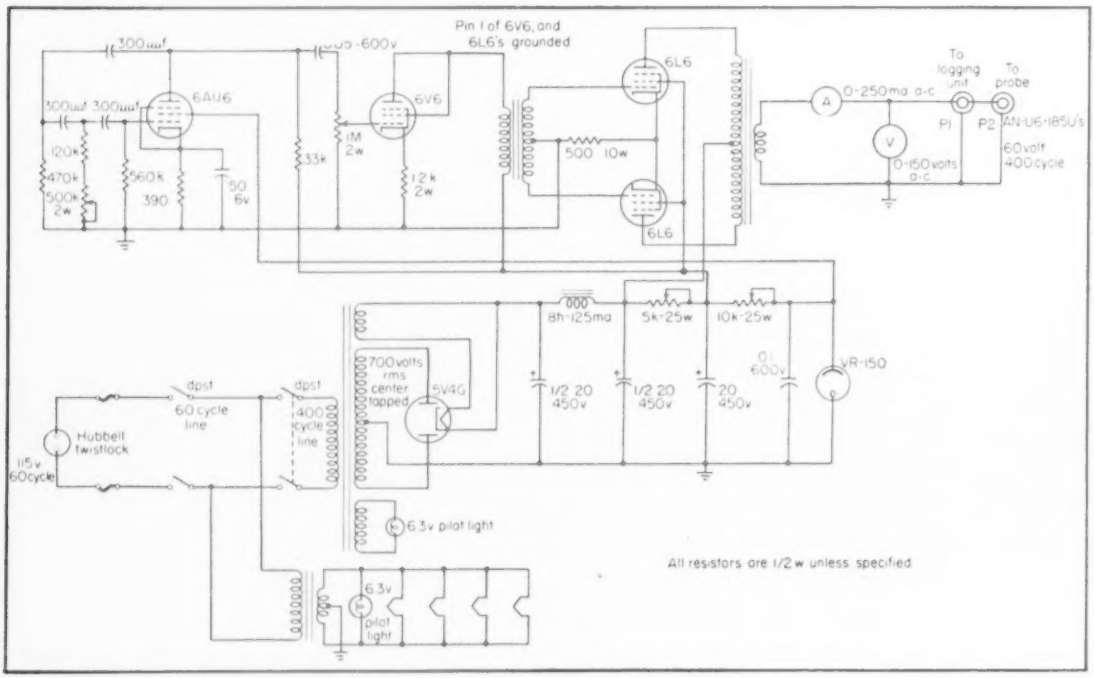

FIG. 3. Circuit of 400-cycle power supply

constant with a ±10% variation in primary voltage. *RC* filtering is used to assure a minimum amount of ripple being applied to the photomultiplier.

To eliminate a coupling capacitor between the photomultiplier tube and the first voltage amplifier, the tap on the voltage divider, at which the last dynode resistor is connected, is grounded. By-passing from the positive side of the high-voltage power supply to this point is necessary.

Filament supply. All tube filaments are connected in series, and total requirements are 31.6 volts at 150 ma. To reduce the energy dissipated in the probe to a minimum, a filament autotransformer is used rather than a series dropping resistor. The transformer was designed by the NYOO around a small hypersil coil. To minimize the stray 400-cycle pick-up, the 12AT7 used in the high-gain voltage amplifier is placed at the lowest a-c potential to ground.

Construction of probe. Figure 5 illustrates the assembled probe ready to be inserted in its stainless-steel housing which is 2 in. in diameter, 0.065 in. wall thickness, and 28½ in. long. O-ring seals make this housing waterproof. The subassemblies are fastened together by two threaded rods with appropriate spacers. A solid stainless-steel bullet nosepiece 3 in. long is used to attenuate head-on radiation, giving the unit a 4-to-1 sensitivity gain in the radial direction.

A specially designed waterproof connector, fitted on the cable, screws into the end of the housing and connects the probe to the surface unit through 1,000 ft of single-conductor double-armored cable.*

Surface Unit

A signal from the cable is passed through a pulse transformer identical in design to the output transformer used in the probe. A series capacitor is again used to discriminate between the 400-cycle power voltage and the signal pulses. Crystal diodes are used at the output of this transformer to eliminate overshoot caused by differentiation of the pulse in the transformers.

An attenuator in the grid circuit of the voltage amplifier is used as a means of pulse-height discrimination; as the attenuation is increased only the larger pulses will be capable of trigger-

* American Steel and Wire.

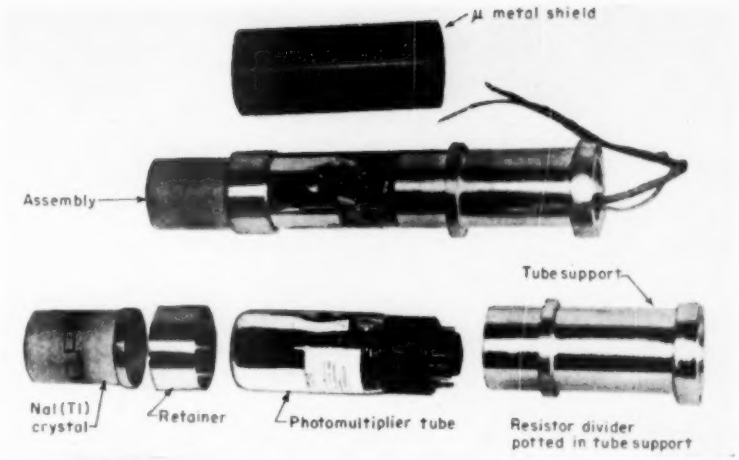

FIG. 4. Detector assembly

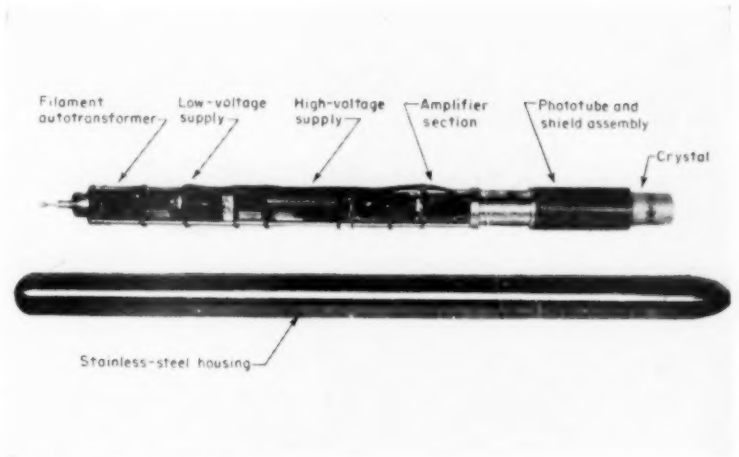

FIG. 5. Scintillation drill-hole probe

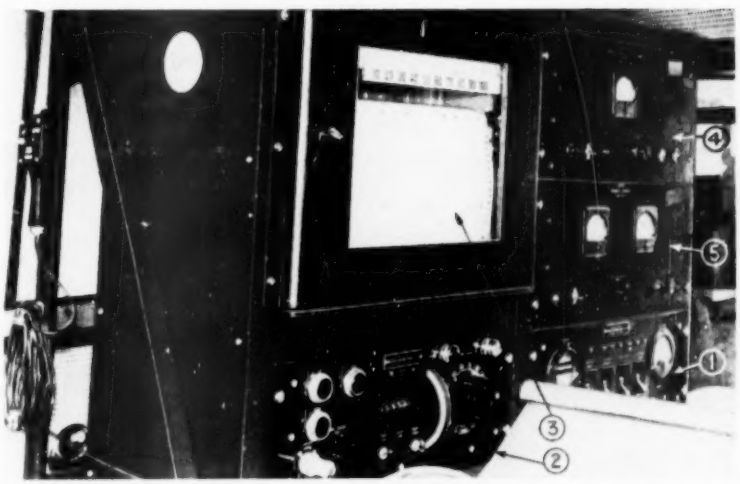

FIG. 6. Control cubicle in Jeep. 1, power panel; 2, motor control and odometer; 3, recorder; 4, surface unit; 5, 400-cycle power unit

ing the univibrator in the following stage. It is thus possible to obtain integral pulse-height data by variation of this attenuator control.

The signal from the attenuators is fed into a single 6AK6 voltage amplifier having a gain of 10. The output of this amplifier is fed through an external coaxial-cable jumper to the univibrator stage. It is possible at this jumper to remove a signal suitable for insertion into a pulse-height analyzer if complete differential pulse-height analysis is desired.

The univibrator is of conventional design and operates from negative trigger pulses. The minimum tripping level is 0.75 volts, which represents an energy level of 30 kev. The output from the univibrator is a 10-μsec pulse of 120 volts. The total deadtime of this circuit is approximately 40 μsec. The unused plate of the univibrator is fitted to an oscilloscope jack for visual observation of the pulses.

A cathode-follower stage is interposed between the univibrator and the integrating circuit to avoid loading of the univibrator and to provide a low source impedance for feeding the integrating circuit. The circuit is arranged so that the amount of charge transferred to the integration circuit is independent of pulse width. The integration time constant is determined by means of a tap switch which varies the value of the integrating resistor.

The voltage from the integrating stage is fed to the grid of a balanced-bridge output stage having exceptionally high stability. A d-c current of one milliampere is used to actuate the indicating instrument; a resistance in series with this instrument provides a voltage drop sufficient to operate a 10-mv potentiometer-type recorder. Full scale ranges of 10, 30, 100, 300, 1,000, 3,000 and 10,000 cps are provided with selectable time constants of approximately ½, 1, 2, 4, 8 and 16 sec. A power supply for this unit operating from a 110-volt 60-cycle source provides the necessary power for operating the surface unit. Voltage regulator tubes are used for circuits requiring such stabilization.

Power supply. Since only 12 watts of 400-cycle power are necessary to supply power to the probe, it was deemed more economical and convenient to design and build a power oscillator operating from 110-volt 60-cycle power rather than resort to rectification, reduction to 28-volt direct current, and the use of a standard rotating type 400-cycle motor-generator set. The power oscillator consists of an *RC* phase-shift type of oscillator feeding a 6V6 buffer into a push-pull 6L6, class AB_2 output stage. The unit was found to be smaller in size, and it is expected to be essentially free of trouble.

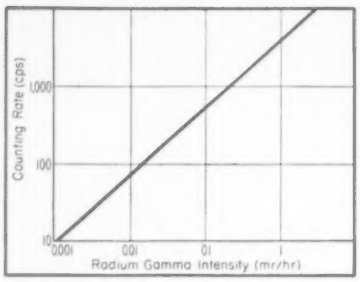

FIG. 7. Typical radium gamma calibration curve for scintillation probe. Correction has been made for background. Sensitivity is set so that 500 cps obtained for 0.1 mr/hr

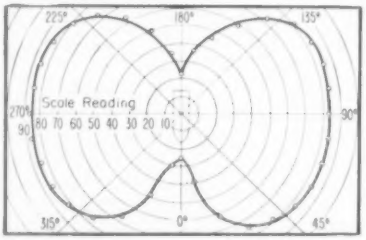

FIG 8. Angular sensitivity in plane of axis of probe shows effect of the stainless-steel nosepiece. This effect improves space resolution of the log by discriminating in favor of radiation adjacent to probe

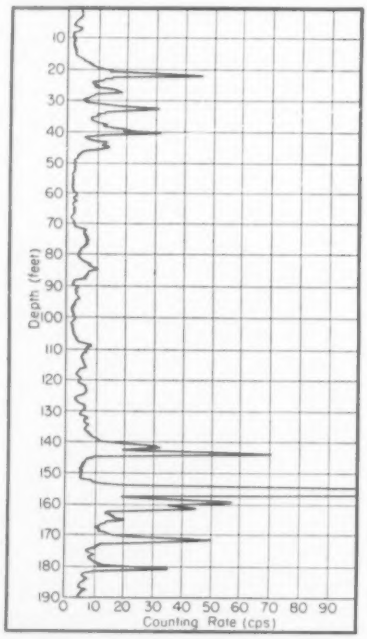

FIG. 9. Typical logging record obtained on the Colorado Plateau. Time constant of 2 seconds was used. Peak between 150 and 160 feet depth was logged at higher rate to obtain better indication; these results are not shown

Mechanical Equipment

Because of the successful operation of the scintillation probe in preliminary field tests, it was decided to build a newly designed series of complete logging units. The electronic equipment, together with motorized cable reel, boom, and auxiliary equipment, was installed in a Willys "Jeep" station wagon. Every convenience was included in the design to facilitate the logging operation.

Power for the logging unit is provided by a 3-kva 110/220-volt 60-cycle generator mounted in front of the vehicle's radiator. This generator is driven from a front power take-off that can be engaged through a special gear box to the engine. A governor is used to maintain constant engine speed when the generator is in use.

The steel cable is wound on a power-driven drum capable of lowering or raising the probe at speeds up to 70 ft/min. Sufficient torque is provided to exert a pull of 150 lb on the cable. A level wind arrangement on this reel insures even wrap of the cable around the drum. The cable then passes from the drum, under the operator's seat, to a telescoping boom that enables the operator to line up the probe with the drill hole through an angle of 270 degrees and a radial adjustment of 2 ft. Locks are provided to fix the boom in position. A pulley at the base of the boom, driven by the cable, measures the length of cable played out. This pulley drives a Selsyn generator that transmits this information to Selsyn motors to drive an odometer dial and the recorder chart drive. Over and under tension limit switches are provided for safety of operation. The boom can be swung over the Jeep and clamped to the roof during transportation.

The cubical in the rear of the Jeep containing the circuitry and controls is shown in Fig. 6. Besides the surface unit and the 400-cycle power unit, it contains a power panel, motor control and odometer, and a recorder.

Power panel. A main 60-cycle 110-volt circuit breaker is provided, together with three branch breakers that feed the electronic circuitry, the reel motor drive, and utility outlets. A voltmeter and frequency meter are provided for checking generator speed. Since the generator is of the saturated-field type, no other controls are necessary.

Motor control and odometer. The drive motor for the reel is a gearhead shunt d-c motor having a flat speed-torque characteristic. The field for this motor is supplied through a selenium rectifier directly from the 110-volt 60-cycle line. Speed control is obtained by using a General Radio Co. Variac variable transformer feeding selenium rectifiers to supply direct current to the armature. Pushbutton operation of a reversing contactor with electrical locking maintains the motor in operation in the desired direction.

A "local-remote" switch transfers control to a hand-held two-position momentary pushbutton switch at the end of a 20-ft cable. The motor can thus be operated from outside the Jeep, facilitating adjustment of the boom over the drilled hole and positioning of the probe to the zero or reference setting.

A register mounted on the front panel is driven by a Selsyn motor synchronized with the odometer-drive Selsyn generator mounted at the base of the boom. Two of the three phases on the Selsyn motor are opened by a switch to allow adjustment of the register zero. The register indicates in tenths of a foot.

Recorder. A standard 10-mv Brown electronic strip-chart recorder has been modified so that the chart drive is obtained from a Selsyn motor also synchronized with the odometer-drive Selsyn. The chart is arranged to traverse 1 in. for 10 ft of probe travel.

Operating Characteristics

Figure 7 is a calibration curve for the probe taken with radium gamma radiation. The data, corrected for background, shows a linear relationship between mr/hr and counts per second over the operating range of the instrument. The sensitivity of this instrument has been set so that 500 cps are obtained for a 0.1-mr/hr dosage. The full scale coverage is therefore from 0.001 mr/hr to 3 mr/hr.

The effect of the stainless-steel nosepiece on the spatial sensitivity of the probe in a plane parallel to its axis can be seen in Fig. 8. The sensitivity is approximately four times greater at right angles to the probe axis than it is on the axis. In use, this effect discriminates against radiation from directions other than adjacent to the probe; this improves the space resolution of the log.

The problem of proper scanning speed resolves itself into, first, a determination of a suitable time constant such that the statistical variation due to the counting rate at any one point in the log is within the desired precision and, second, the selection of a logging speed such that the rate of change of the activity is small compared to the selected time constant. Based on this premise, it is obvious that no optimum scanning rate can be specified for all conditions.

For lithological data in barren ground, the average counting rate will be relatively small, requiring longer time constants for a given precision. Consequently slower logging speeds are necessary. In ore, the counting rate will be considerably higher, making it possible to utilize much shorter time constants and faster logging speeds.

Utilizing the scintillation counter, satisfactory lithologic logs have been obtained at rates up to 15 or 20 ft/min. In ore, usable logs have been obtained at logging rates as high as 60 ft/min. As an average rate covering both lithology and ores, a logging speed of from 20-30 ft/min has been found to be a good compromise. A typical log obtained in the Colorado Plateau region is shown in Fig. 9.

Ore identification. It was recognized at an earlier stage that ability to analyze the radioactive material in the hole by means of a gamma-energy-sensitive device would make it possible to eliminate coring. Visual inspection of the pulse-height spectrum in test borings by means of a triggered-sweep oscillograph revealed that gamma-ray spectrum differences could be clearly distinguished.

Laboratory tests indicated that the resolution observed is sufficiently good to identify the spectra of different isotopes. Figure 10 shows, respectively, the spectra of pitchblende containing uranium and radium, Brazilian monazite containing thorium, and calibrating spectra of the artificial isotopes of cobalt-60 and cesium-137. Where several oscillograms appear on one figure, the exposure time has been varied so that both the strong and weak lines of the spectrum can be observed.

* * *

The mechanical and electrical design and installation of the equipment in the Jeep was done by Bogue Electric Co., under AEC specifications and inspection.

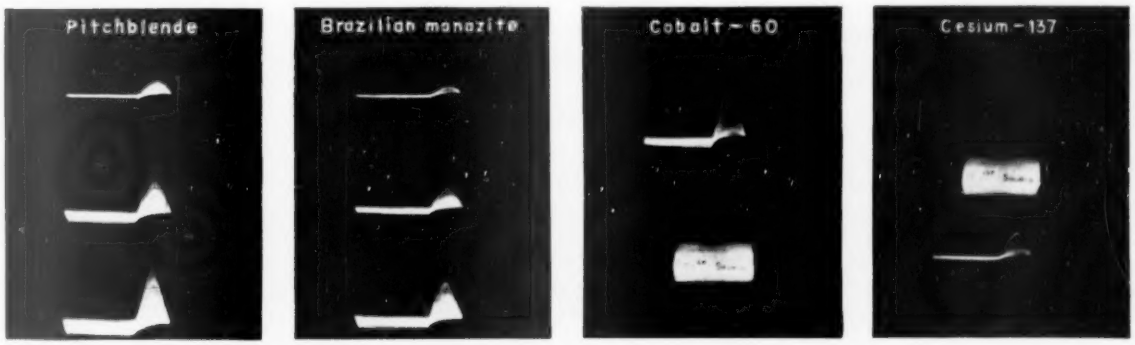

FIG. 10. Pulse-height spectra from ores and isotope sources

Production of Nuclear Fuels by Induced Radioactive Chains

Careful balance is necessary among recovery efficiency, reactor power level, and exposure time for large-scale production of decay-product isotopes. These production problems are discussed, with quantitative application to Pu-239 and U-233

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LARGE-SCALE PRODUCTION of artificial isotopes that result from a radioactive chain induced by neutron irradiation in a reactor is a complex undertaking. Proper choice of operating conditions requires detailed analysis of the pertinent reaction kinetics.

The detailed consideration given here for the production of large quantities of Pu^{239} and U^{233} is greatly facilitated by the happy circumstance of the relative magnitudes of the decay constants in the reactions involved; production of other substances may require involved computational effort.

As will be shown, it is fairly certain that for production of 1-kg quantities of Pu^{239} and U^{233}, reactor power levels not much more than 200 and 32 Mw, respectively, are called for in the irradiation of feed materials in the reactor.

Another important factor that prescribes the over-all time which must elapse prior to actual chemical separation of the final product is the ultimate recovery efficiency required; excessive aging times to allow radioactive decay of intermediate nuclides are needed for recovery efficiencies greater than 99%.

Because the conversion $Np^{239} \rightarrow Pu^{239}$ is more rapid than $Pa^{233} \rightarrow U^{233}$, it appears that rapid stock-piling of nuclear fuel calls for irradiation of natural uranium rather than thorium, until some future time when uranium supplies may become depleted.

Reaction Kinetics

One can show that for the induced radioactive chain

$$x \xrightarrow{k_0} x_1 \xrightarrow{\lambda_1} x_2 \xrightarrow{\lambda_2} x_3$$

where x is the progenitor of radioactive offspring x_1 and x_2, which have decay constants λ_1 and λ_2, the quantities of the newly formed members are given by

$$x_1 = (k_0/\lambda_1)(1 - e^{-\lambda_1 t}) \quad (1)$$

$$x_2 = (k_0/\lambda_2)\left(1 + \frac{\lambda_2}{\lambda_1 - \lambda_2} e^{-\lambda_1 t} - \frac{\lambda_1}{\lambda_1 - \lambda_2} e^{-\lambda_2 t}\right) \quad (2)$$

$$x_3 = k_0\left[t - \frac{\lambda_2}{\lambda_1(\lambda_1 - \lambda_2)}(e^{-\lambda_1 t} - 1) + \frac{\lambda_1}{\lambda_2(\lambda_1 - \lambda_2)}(e^{-\lambda_2 t} - 1)\right] \quad (3)$$

where k_0 is the initial transmutation rate, which is assumed to be invariant during the course of the irradiation.

The constancy of k_0 may be maintained by using excessively large quantities of x to produce high dilutions of x_3, or by replenishing x in continuous fashion (as may be done if x takes the form of a circulating fluid). A fixed rate of conversion of the parent implies a constant power level of operation.

The end product, x_3, is the stable (or at least quasi-stable) isotope ultimately to be isolated. Then, from Eqs. 1, 2, and 3, the potential total quantity of yield at any time is

$$Y = \sum_{n=1}^{3} x_n \quad (4)$$

Determination of this yield and the relative amounts of the various daughters during the course of exposure may be done for certain defined systems.

For the production of Pu^{239} and U^{233}, the calculation is simplified since, for these two cases, $\lambda_1 \gg \lambda_2$. Thus $x_2 \gg x_1 \ll x_3$ for reasonable values of t (there is little point in considering operating times less than 24 hr), and

$$x_2 = (k_0/\lambda_2)(1 - e^{-\lambda_2 t}) \quad (5)$$

$$x_3 = k_0[t - (1/\lambda_2)(1 - e^{-\lambda_2 t})] \quad (6)$$

Application to U^{233}, Pu^{239}

Thorium is transformed into U^{233} according to the reactions (*1*)

$$Th^{232}(n,\gamma)Th^{233} \xrightarrow[23m]{\beta^-} Pa^{233} \xrightarrow[27.4d]{\beta^-} U^{233}$$

The conversion of U^{238} into Pu^{239} follows a course similar to this. Table 1 shows the decay constants for the two processes and the half-lives from which the decay constants are calculated.

In both cases the half-life of the second beta decay is considerably

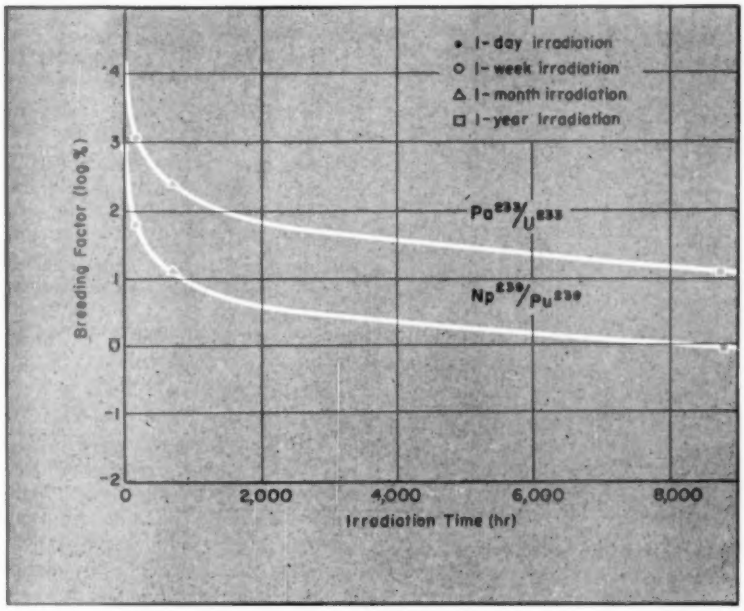

FIG. 1. Breeding factors during irradiation period

longer than that of the first beta decay, and the decay constant of the second stage is much smaller than that of the first. Thus for both Pu^{239} and U^{233} production, the hold-up is in the last beta decay stage, with the situation much more severe for U^{233}.

The hold-up in reaching the ultimate accumulation of the final product may be gaged by taking the ratio x_2/x_3. From Eqs. 5 and 6 it is evident that this ratio ranges from ∞ to 0 as t goes from 0 to ∞. The breeding ratios Pa^{233}/U^{233} and Np^{239}/Pu^{239} throughout the irradiation period can be estimated from Fig. 1.

It is at once evident that the accelerated production of nuclear fuels is limited by appreciable hold-up and that the best one can hope for is a cumulative reaction time at least equivalent to an aging period. For 99% conversion, this aging period approaches 6.63 half-lives (*2*); for Pu^{239} manufacture, this amounts to some 15 days, and for U^{233} it is 182 days.

TABLE 1—Constants for Pu-239 and U-233 Production

Constants	$U^{238} \rightarrow Pu^{239}$	$Th^{232} \rightarrow U^{233}$
λ_1	1.81	1.81
λ_2	0.0126	0.00106
$t_{\frac{1}{2}}$	23 m	23 m
$t'_{\frac{1}{2}}$	2.3 d	27.4 d

Thus there is a practical limit to the rate of production of these fissionable materials which makes further extension of the power level of operation needless.

Figure 2 shows the available yields of Pu^{239} for selected intervals of reactor operation at diverse levels of operation. Since, in general, $Y = k_0 t$, Eq. 4 may be reduced to

$$x_1 + x_2 + x_3 = k_0 t \qquad (7)$$

which has been used for the calculation. The power level of the reactor for converting k_0 atoms of the feed material each second into the isotope one mass number higher is $3.2 \times 10^{-11} k_0$ watts, where the conventional value of 200 Mev per fission of U^{235}, and a neutron multiplication factor greater than unity have been assumed.

Thus for the Oak Ridge reactor, running at 2,000 kw, k_0 is about 6×10^{16} atoms/sec, which means that it will take at least a year to produce 1 kg of Pu^{239}; comparatively little or no aging time is required since $Np^{239}/Pu^{239} < 0.01$ (Fig. 1).

For low neutron absorption, it is usual to make the approximation $k_0 \approx \phi\sigma N$, where ϕ is the neutron flux, σ is the cross section for the reaction $U^{238}(n,\gamma)U^{239}$, and N is the number of U^{238} atoms exposed. For a flux of 10^{12} $n/cm^2/sec$ (the average flux of the Oak Ridge reactor) and a value of $\sigma = 2 \times 10^{-24}$ cm^2, a simple calculation shows that there are about 3×10^{28} U^{238} atoms (16 tons) in the reactor.

Although the notation of Fig. 2 has been specified for Pu^{239}, the figure is virtually the same for U^{233}. The over-all time is, of course, markedly different for the latter. It is essential to make use of Fig. 2 in conjunction with Fig. 1, which implies the aging requirements.

Use of the Oak Ridge reactor to produce kilogram quantities of Pu^{239} is limited by the high loss of yield that results from the relatively high concentration factor which favors the fission of the product itself. To suppress loss of Pu^{239}, it is necessary to assure adequate dilution by incorporating excessive amounts of feed material. It would seem that a scheme involving continuous removal of the product as it is formed could be devised to eliminate this limitation.

To get a total accumulation of 1 kg of Pu^{239} per month requires a reactor of about 30 Mw. Before aging, the sample would contain 1 gm of Np^{239}, so an additional wait of 15 days before chemical treatment would be required for 99.9% reclamation of Pu^{239}. A reactor operating at about 100 Mw creates a potential supply of 1 kg of Pu^{239} in about a week. In this instance, almost 50% of the unaged product is Np^{239}, and an even greater storage period is needed for a recovery level of 99.9%.

Thus, intensifying the irradiation by augmenting the operating power of the reactor, although it leads to a reduction of the breeding time, results in progressively larger aging intervals, the magnitude of which depend on the recovery efficiency desired.

Release Time and Hold-Up

An important factor in the resultant over-all time which precedes the actual chemical processing and separating of the metal is the precise level required of the recovery efficiency. The interesting aspect of this problem is the quantitative description of the interaction of the conflicting elements of recovery efficiency and speed of releasing reacted uranium for the follow-up stages in the process of turning out metallic plutonium.

Suppose that after an irradiation of duration t_p the amount of intermediate daughter, Np^{239} or Pa^{233}, is

$$x_2 = (k_0/\lambda_2)(1 - e^{-\lambda_2 t_p})$$

Then, if the recovery efficiency is to be

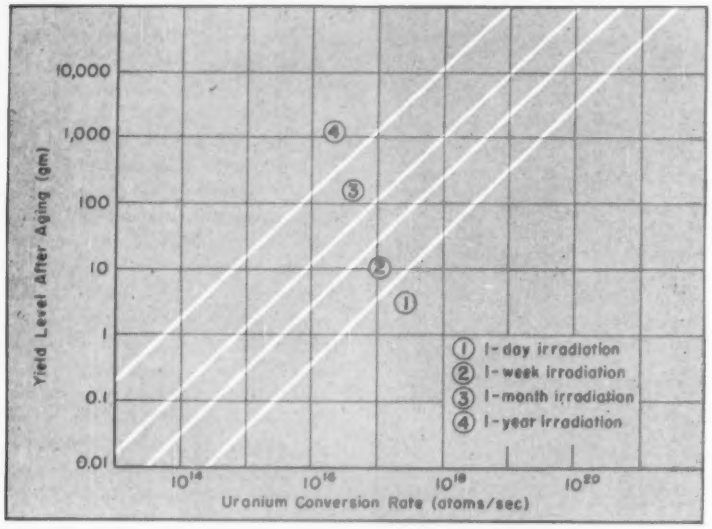

FIG. 2. Yield level of plutonium as a function of conversion rate of uranium

ϵ for a yield level y, the aging or storage time, t_s, required can be found from the decay relation

$$\frac{y(1-\epsilon)}{(k_0/\lambda_2)(1-e^{-\lambda_2 t_p})} = e^{-\lambda_2 t_s}$$

The solution of this is

$$t_s = \frac{1}{\lambda_2 \log e} \log \left[\frac{(k_0/\lambda_2)(1-e^{-\lambda_2 t_p})}{y(1-\epsilon)} \right] \quad (8)$$

This result may be written more conveniently in terms of reactor power, P, where, in general,

$$t_p = ny/P \quad (9)$$

The term n is the appropriate conversion factor from the relation $P = nk_0$. Hence an equivalent expression for Eq. 8 is

$$t_s = \frac{1}{\lambda_2 \log e} \log \left[\frac{P(1-e^{-\lambda_2 ny/P})}{\lambda_2 ny(1-\epsilon)} \right] \quad (10)$$

A useful index of the retardation imposed by a prescribed recovery efficiency is the ratio t_s/t_p, which can be termed the hold-up factor. Another significant parameter is the over-all time elapsed before the feed material is ready for actual separation of the desired product. This quantity, called the release time, t_r, is

$$t_r = t_p + t_s = ny/P + \frac{1}{\lambda_2 \log e} \log \left[\frac{P(1-e^{-\lambda_2 ny/P})}{\lambda_2 ny(1-\epsilon)} \right] \quad (11)$$

Table 2 is a list of pertinent data for the synthesis of Pu^{239} and U^{233}. The first four columns require no particular comment at this point since reference has been made to these in the form of Figs. 1 and 2. In the last three columns are listed the aging interval, t_s, the release time, t_r, and the hold-up factor, t_s/t_p, for three recovery levels, 99.9%, 99.0%, and 90%. Results for other recovery efficiencies may readily be obtained by graphical means.

Release time and power. The most striking point shown in Table 2 is the fact that the release period very precipitously transforms from a highly power-sensitive quantity to one which is relatively invariant. Figure 3 shows the release period (including irradiation and aging time) as a function of power. For Pu^{239} the threshold power for 1-kg yields is about 200 Mw; this would seem to be the lower limit of reactor power for such quantities of nuclear fuel. Smaller yields are compatible with lower power. A rough rule of thumb appears to be a threshold power proportional to yield level. Use of higher power levels results in comparatively little saving of time.

Some interesting comparisons may be made by noting the variation in release period for U^{233} production as shown in Fig. 3; whereas the threshold for Pu^{239} was some 200 Mw, for U^{233} it is only about 32 Mw. For Pu^{239} the

TABLE 2—Parameters for Pu-239 and U-233 Production for 1-kg Yields

Irradiation time, t_p (hr)	*Conversion rate, k_0 (sec^{-1})*	*Reactor power, P (Mw)*	*Breeding factor (x_2/x_3)*	*Storage time, t_s (hr)*			*Release period, t_r (hr)*			*Hold-up factor, t_s/t_p*		
				Recovery efficiency (%)			*Recovery efficiency (%)*			*Recovery efficiency (%)*		
				99.9	*99.0*	*90.0*	*99.9*	*99.0*	*90.0*	*99.9*	*99.0*	*90.0*
Reaction: $U^{238}(n,\gamma)U^{239} \xrightarrow{\beta^-} Np^{239} \xrightarrow{\beta^-} Pu^{239}$												
24	2.93×10^{19}	938	6.25	533	352	169	557	376	193	22.2	14.7	7.04
48	1.46×10^{19}	469	3.04	525	343	160	573	391	208	10.9	7.14	3.34
168 (week)	4.18×10^{18}	134	0.62	472	289	107	640	457	275	2.82	1.72	0.636
720 (month)	9.73×10^{17}	31.1	0.12	374	191	7.6	1,094	911	728	0.52	0.27	0.011
2,400	2.93×10^{17}	9.4	0.034	278	95	0	2,678	2,495	2,400	0.12	0.040	0
8,760 (year)	8.00×10^{16}	2.6	0.0031	175	0	0	8,935	8,760	8,760	0.020	0	0
Reaction: $Th^{232}(n,\gamma)Th^{233} \xrightarrow{\beta^-} Pa^{233} \xrightarrow{\beta^-} U^{233}$												
168	4.29×10^{18}	137	11.3	6,440	4,270	2,090	6,608	4,438	2,258	38.3	25.4	12.5
240	3.00×10^{18}	96	7.20	6,415	4,230	2,060	6,655	4,470	2,300	26.7	17.7	8.60
720	1.00×10^{18}	32	2.34	6,180	4,010	1,835	6,900	4,730	2,555	8.60	5.58	2.55
2,400	3.00×10^{17}	9.6	0.57	5,550	3,395	1,216	7,950	5,795	3,616	2.31	1.42	0.51
8,760	8.21×10^{16}	2.6	0.12	4,415	2,248	69	13,175	11,008	8,829	0.50	0.26	0.0079

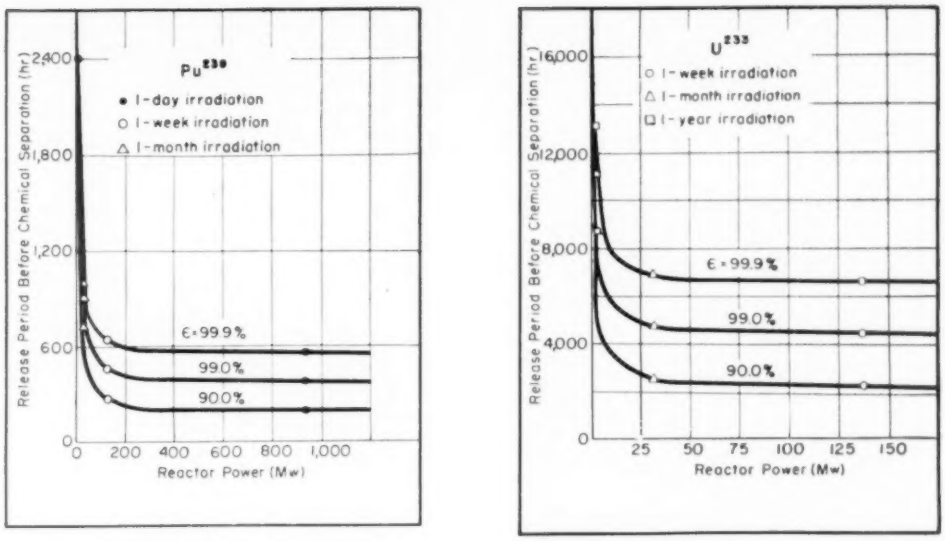

FIG. 3. Release period before chemical separation as a function of reactor power

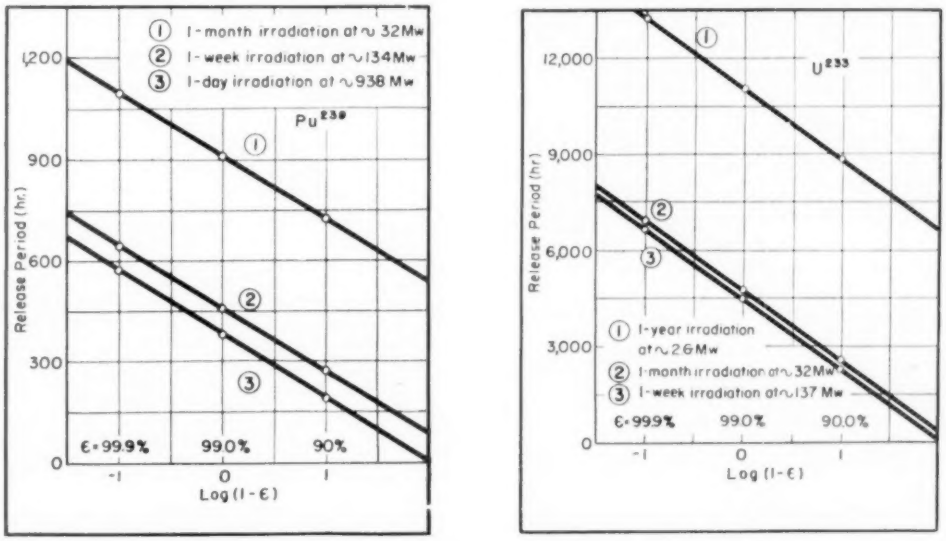

FIG. 4. Role of recovery efficiency in prescribing release period for potential yield of 1 kg

release interval ranges from 640 to 275 hr for a recovery efficiency variation of 99.9 to 90%, and for U^{233} the release interval is 6,900 to 2,555 hr for the same variation of recovery efficiency. These figures are to be taken as nominal operating conditions for these nuclear fuels. Regardless of the power level of operation, the conversion of ordinary thorium to the fissionable U^{233} is inherently a much slower process than the synthesis of Pu^{239} from natural uranium.

Release time and recovery efficiency. For an examination of this dependence, it is convenient to rewrite Eq. 11 in the form

$$t_r = A - \frac{1}{\lambda_2 \log e} \log (1 - \epsilon) \quad (12)$$

where

$$A = \frac{ny}{P} + \frac{1}{\lambda_2 \log e} \times \log \left[\frac{P(1 - e^{-\lambda_2 ny/P})}{\lambda_2 ny} \right]$$

Thus, for constant yield and power, a plot of t_r vs $\log (1 - \epsilon)$ should be linear with slope $-1/\lambda_2 \log e$ and intercept A. Figure 4 shows that this is indeed the case. These graphs should be helpful in arriving at suitable compromise arrangements for production rates, quantities of yield, and by-product reclamation of fission wastes.

Hold-up factor and power. The relative amount of time spent in irradiating the feed material, compared to the aging period, at various power levels is shown in Fig. 5 for different recovery efficiencies. The hold-up factor is seen to be linearly related to the power, within the desirable confines of operation above the threshold regions previously described.

From Eqs. 8 and 9, the hold-up

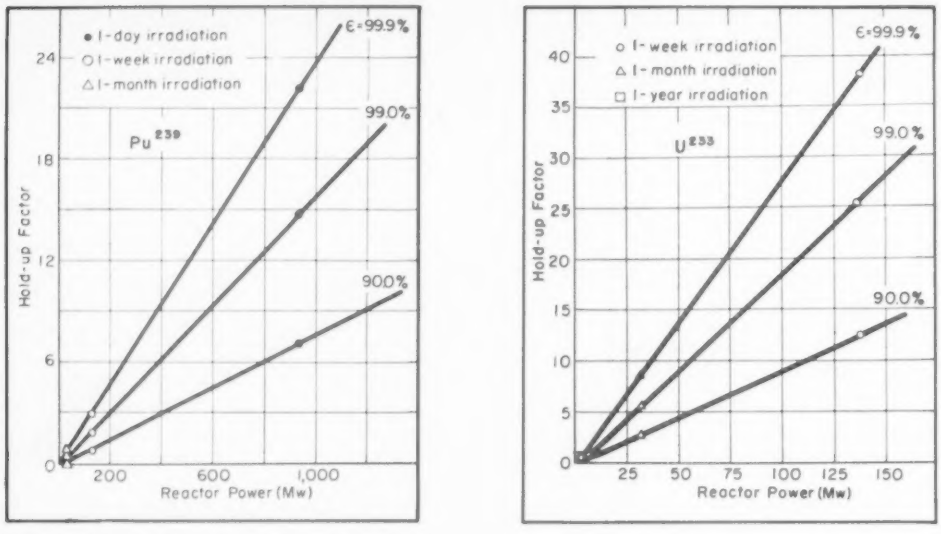

FIG. 5. Hold-up factors as functions of reactor power

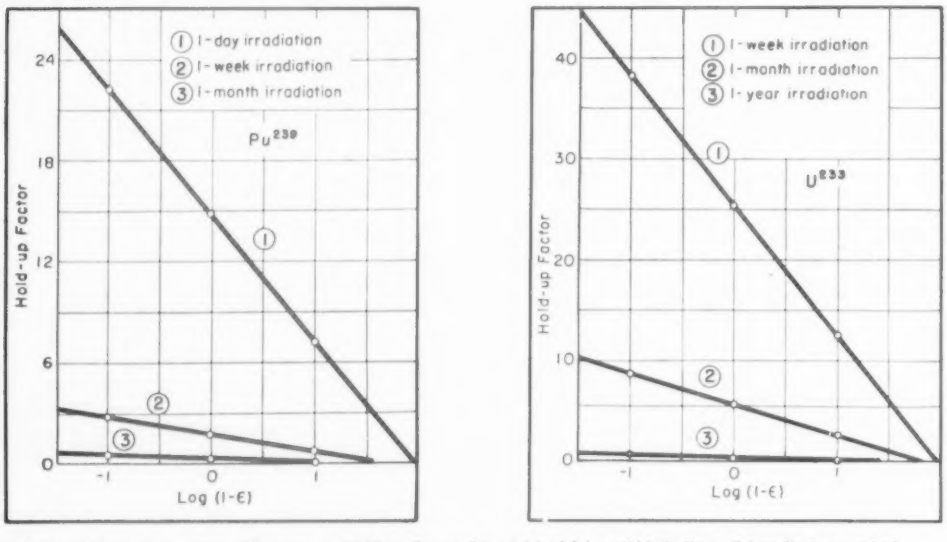

FIG. 6. Effect of recovery efficiency on hold-up factor for yield of 1 kg within indicated irradiation period

factor can be written in the form

$$t_s/t_p = aP + \log [bP(1 - e^{-c/P})]$$

where

$$a = \frac{1}{ny\lambda_2 \log e}; \quad b = \frac{1}{ny\lambda_2(1 - \epsilon)};$$
$$\text{and} \quad c = ny\lambda_2$$

Thus, for large values of P, we have $t_s/t_p \simeq aP$, and the slopes of the straight lines in Fig. 5 are $1/ny\lambda_2 \log e$.

Hold-up factor and recovery efficiency. The general behavior of the hold-up factors in terms of variations of recovery efficiency is shown in Fig. 6 for three different irradiation periods. For Pu^{239}, the hold-up factor as a function of recovery efficiency rapidly becomes insignificant for irradiation times between 1 week and 1 month; for U^{233} the reduction to negligible values occurs for irradiation periods of about a year.

The character of the straight lines of Fig. 6 becomes apparent if the hold-up factor is written as

$$t_s/t_p = -A \log (1 - \epsilon) + B$$

where $A = P/ny\lambda_2 \log e$ and

$$B = A\left[\log \frac{P}{ny\lambda_2} + \log (1 - e^{-ny\lambda_2/P})\right]$$

Thus it is immediately evident that the slopes become steeper for the abbreviated exposure times, i. e., at greater reactor power levels.

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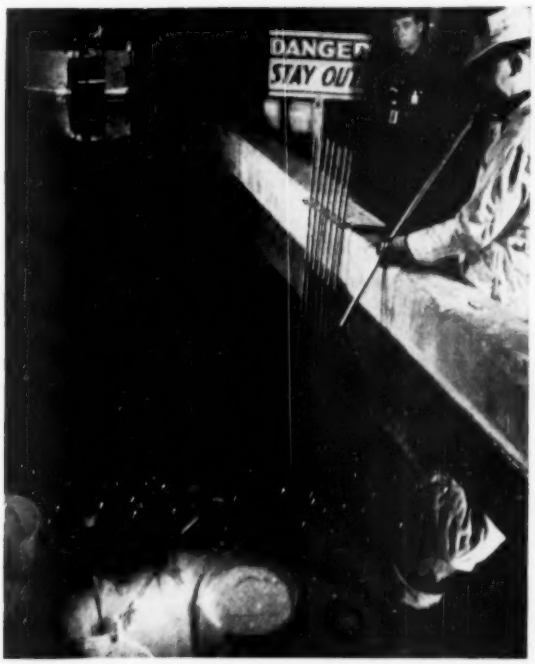
Handling Multicurie Reactor Products

THE PROBLEM of temporary storage of spent uranium fuel slugs from the Oak Ridge graphite-uranium reactor is solved by keeping them in buckets in a water-filled canal beneath the reactor. The water provides sufficient shielding against the activity of the slugs. Contaminated equipment is also stored in the canal. Slugs are later removed and transferred to another building for chemical extraction of fission products. An electric chain hoist on an overhead track is used to move heavy loads in the canal.

SPENT FUEL SLUGS from reactor are kept in underwater buckets. Health-physicist is checking radioactivity level

WATER-FILLED CANAL into which radioactive slugs fall when ejected from reactor. Water depth ranges from 9 to 20 ft



LONG TONGS are used to remove uranium slugs from underwater bucket for loading into shielded transfer container

FIG. 1. Isodose recorder and associated equipment

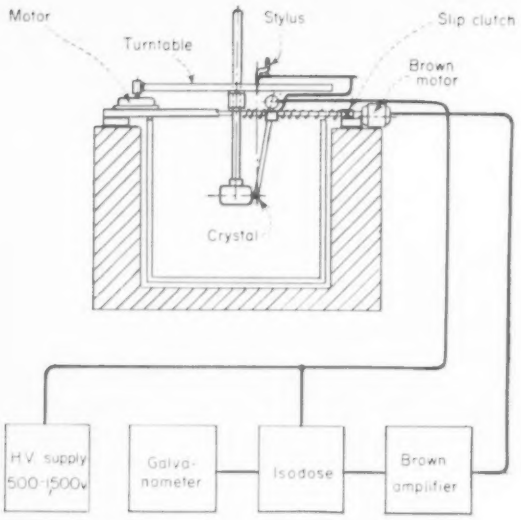


FIG. 2. Schematic drawing of isodose recorder

A Simplified Automatic

This low-cost isodose recorder has proved reliable for γ-ray therapy studies after one year's operation. The recorder, which can be applied to full-scattering mediums, has a maximum sensitivity of 3 r/hr with an error of 5%

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IN GAMMA-RAY THERAPY, complex configurations of radium or radiocobalt sources are often used. The theoretical determination of surfaces of equal dose is slow and often difficult. The experimental determination of these surfaces by ionization chamber methods is likewise time consuming, and subject to error if the chamber volume cannot be considered a point approximation (*1*).

An automatic isodose recorder, employing a scintillation counter with a small detecting crystal, has been described by Hine, Berman, and Elkind (*2*). The isodose recorder described here is similar in some aspects but embodies both mechanical and electrical simplifications. In addition, the simplified method allows accurate measurements in roentgens in a full scattering medium.

Description

The recorder is shown in Fig. 1. Sources are mounted on the shaft of a recording turntable 15 cm in radius which is rotated at ¼ rpm. Beneath the turntable, the scintillation probe, with a small crystal at the end of a light-pipe extension, can be moved radially by a drive screw (¾-in. diameter, $\frac{1}{20}$-in. pitch) which is coupled to the Brown motor through a slip clutch (Fig. 2).

When the instrument is set for an isodose, the crystal is driven toward the sources if the measured dose rate tends below the preset level and away from the sources when it tends above the preset level. A direct linkage between the probe and a stylus, which is adjusted to lie directly above the crystal position, assures an accurate recording of these movements on the coordinate paper. Thus, as the turntable rotates, a particular isodose curve in a plane perpendicular to the axis of rotation is traced (Fig. 3). Different planes are selected by the vertical adjustment of the turntable shaft. The complete isodose surface can then be constructed from a set of planar isodose curves.

Operation

A semispherical anthracene crystal, 1.5 mm in radius, is used as the detecting element. It is mounted with the plane surface facing the phototube at the end of a polished aluminum light pipe. This aluminum tube (20 cm long, 3-mm inside diameter, 1-mm wall

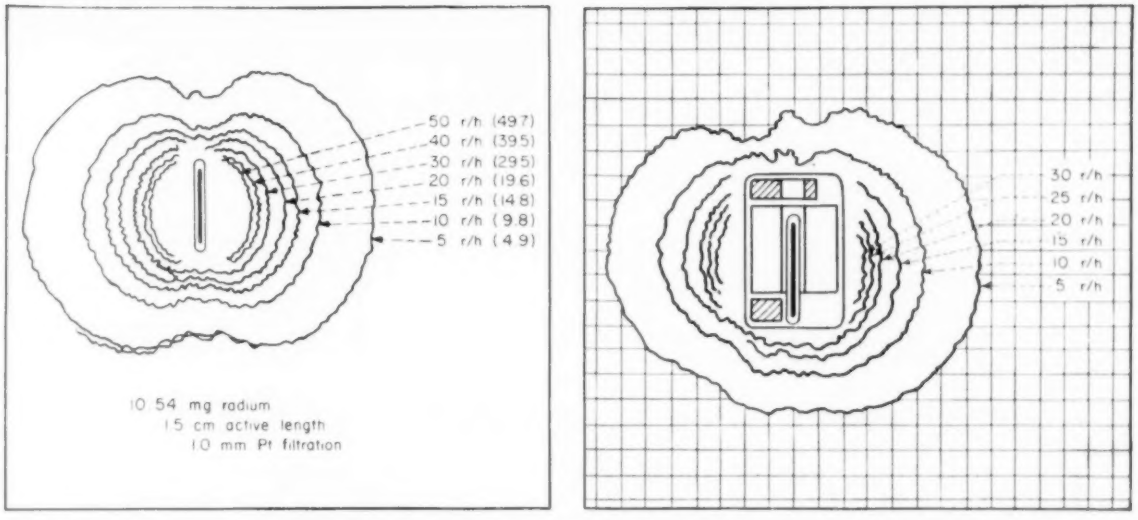

FIG. 3. Isodose tracings. **Left, 10-mg Ra source; right, gynecological Ra applicator. Asymmetry of applicator curves is caused by tungsten screening; values in parentheses are calculated**

Isodose Recorder

thickness) transmits light to a 1P28 photomultiplier tube, selected for high sensitivity and low dark current.

The integrated anode current, which is taken as a measure of the gamma-ray dose rate at the position of the crystal, flows through the $R_1R_2R_3$ resistor network (Fig. 4). R_1 and C_1 serve to filter out transient variations. The anode current through R_2 is opposed by a selected current from the isodose selector resistance network, the combined voltage drop being fed to the Brown amplifier and thence to the Brown motor which moves the scintillation probe and stylus.

Balance of the small dark current is effected independently of the selected opposing current by potentiometer R_4. The polarity of the input voltage of the Brown amplifier determines the direction of rotation of the Brown motor. Hence, when the anode current (dose rate) rises above the selected opposing current, the motor will turn in a direction so as to move the crystal away from the sources; as the anode current falls below the fixed current, the motor is driven in the reverse direction and moves the crystal closer to the sources.

As the sources rotate, the crystal is maintained in a position of constant dose rate. The measured anode current is constantly monitored by the galvanometer (0.25 μa full-scale deflection). Sensitivity is adjusted by changing the voltage applied to the photomultiplier—maximum practical full-scale sensitivity being 25 r/hr. The minimum dose rate that can be traced as an isodose curve is 3 r/hr.

Calibration. The primary calibration is in air at various distances on the basis of calculated dose rates from a standard 10-mg radium source. A convenient secondary standard is a 1-mg radium needle mounted in a Lucite cap that slips over the end of the probe and holds the needle in a fixed geometry relative to the crystal (Fig. 3). Such a source can provide 25 r/hr at the point of the crystal.

Detector size. A crystal of the size used here can be considered a point approximation up to 1 cm from a 1.5-cm linear source. Experiment shows that the measured intensity, when compared to the calculated dose rate, is only 3% in error at this distance. The point-approximation error becomes increasingly larger at closer distances. However, the probe position cannot be determined within 0.1 mm. Hence, the error in mechanical positioning is comparable to the error introduced by crystal volume, and one cannot be separated from the other experimentally. Therefore, there is no advantage in using a crystal smaller than about 0.005 cm³ with this unit.

Light pipe. The error caused by radiation striking the photocathode of the photomultiplier tube is reduced to a few per cent by separation of radiator and tube with the 20-cm light-pipe extension. A small lead shield would further reduce this error.

A Lucite-rod light pipe introduced errors sometimes larger than 5% due to scintillations of the Lucite itself. A well-polished aluminum tube 20 cm long transmits at best 35% of the incident-light flux as against 97% for a Lucite rod (measured on a MacBeth-Ansco densitometer), but completely removes the rod scintillation error. In addition, the number of optical interfaces is reduced so that the relative efficiency may be somewhat better than this figure.

Backing the crystal with MgO powder to provide a diffuse reflector again increases the efficiency. An

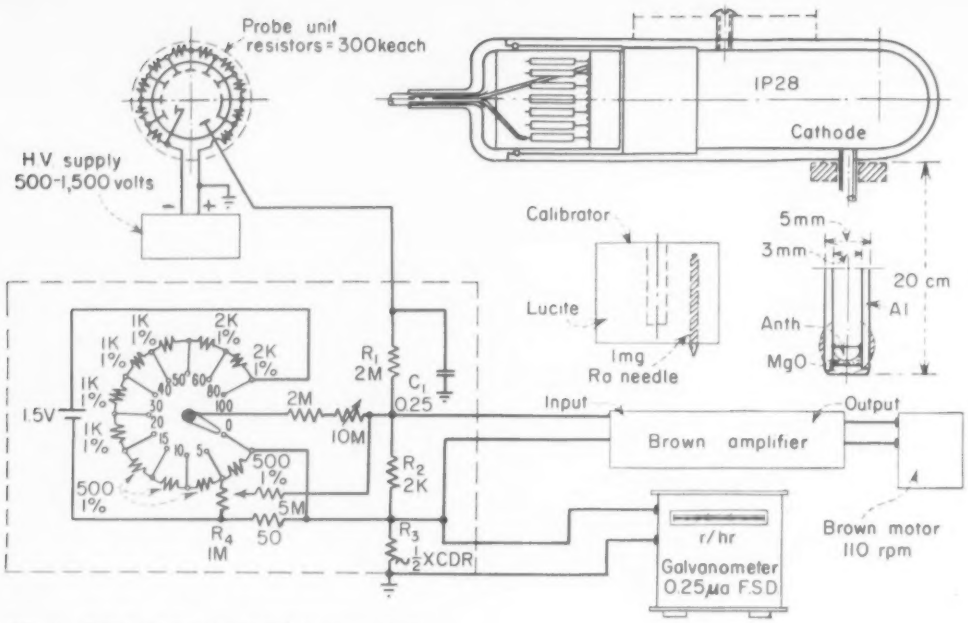

FIG. 4. Details of probe unit and isodose selector

aluminum light pipe used this way will have one half the efficiency of Lucite without the MgO backing.

Current vs energy absorbed. Hopkins has shown that the amplitude of the light pulse emitted by an anthracene crystal that totally stops an electron is strictly proportional to electron energy for 0.125–3.2 Mev, and fairly proportional below 0.125 Mev. All but a small percentage of the initial distribution of the Compton electrons from Co^{60} and radium are greater than 0.125 Mev (*3*).

Since the anode current of a photomultiplier is proportional to the incident light flux, it is apparent that the integrated anode current is a measure of the total energy absorbed from the electrons by the crystal. This energy will be proportional to roentgens if the photon absorption of the crystal corresponds to that of air. The proportionality of anode current to roentgens has been shown to be true providing the crystal is airlike for the photon energies measured (*4, 5*).

Crystal material. Meaningful measurements around gamma-ray sources in water phantoms require that the crystal be airlike over the range of gamma-ray energies present. Between 0.12 and 3.2-Mev photon energies, anthracene is airlike to within 2% (*6, 7*), so that it is perfectly suited to gamma-ray measurements in phantoms. When work is restricted to within 10 cm of gamma sources in air, the wavelength does not vary appreciably, and a nonairlike crystal of higher sensitivity (thallium-activated KI) may be used to advantage.

Cap material and thickness. Electronic equilibrium must be effected if the crystal is to give an output always proportional to roentgens, e.g., as in an ionization chamber the number of secondary electrons entering the active volume must equal the number leaving. For radium and cobalt gamma rays, this condition is approximately met when the crystal is imbedded in a material with atomic number between 7 and 13 and of thickness equal to the range of the secondary electrons (*8*). Hence, the use of a MgO reflector and an aluminum cap of 1.5-mm thickness can be expected to give favorable results.

Careful measurements with an anthracene crystal used in this manner agree with air-wall ionization chamber measurements within the experimental accuracy around Ra and Co^{60} sources in air and in water.

Linearity and stability. The integrated current of the scintillation probe has been found to be proportional to the dose rate over the entire intensity range measured. If the phototube is allowed to "warm up" for several hours, the dark-current drift and change of sensitivity are negligible. Photomultiplier fatigue is not evidenced because of the small currents drawn from it (less than 0.5 μa). A well regulated voltage of from 500 to 1,500 volts should be supplied to the tube. There is an optimum position of the gain control of the Brown amplifier for each isodose level recorded which is sufficient to allow accurate tracking, but low enough to prevent oscillation of the crystal about the intended curve.

Because of the simplicity of the recorder, the initial and maintenance costs are small. Over a period of one year of operation, the instrument has proved to be an easily used and reliable performer, and with moderate experience one can in a short time record complete isodose curves that are less than 5% in error.

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Design of Extended-Source Scintillation Detectors

A light-collecting cylinder, interposed between the phosphor and a 1P21 photomultiplier, reduces survey time with the scintillation detector by one half. For best results, the product of the detector's counting rate and sensitive area must be maximized by choosing the correct cylinder length and diameter

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FOR FIXED-POSITION instruments used to detect the lowest possible level of radiation coming from an extended area, the detector should be designed for the greatest sensitivity, e. g., maximum counting rate. However, for survey instruments, a design that minimizes the survey time is desired—this design does not necessarily produce maximum sensitivity. We have attempted to determine the design criteria for instruments used in extended-source measurements, as described in a preliminary report (*1*).

Although photomultiplier tubes with large light-sensitive areas, e. g., the RCA 5819 and RCA BS-201, have improved detection of ionizing radiation from extended sources, the problem remains to obtain maximum detection efficiency.

To improve the field of view of the RCA 5819, Bell (*2, 3*) used a truncated Lucite cone 6 in. long to conduct light from scintillations at the base to a 1.5-in.-diameter photosensitive cathode at the top. The base of the cone was 3 in. in diameter and the top was 1.5 in. in diameter. This arrangement resulted in a 50% decrease in pulse heights. A similar scheme was used at Chalk River Laboratory (*1*), employing a cone with a phosphor coating on the 2-in.-diameter base. Here, too, a 50% loss was reported. With a 3-in.-diameter base, the system was unusable.

In neither of these cases was it reported whether or not any attempt had been made to determine the conditions giving the best performance of the system.

Design Principle

If a number of counts N is considered necessary to give a significant indication, and if a detector of sensitive area a has a counting rate C when placed in position on a flat, uniform, extended radioactive source of area A, then the time T required to survey the area A is expressed as

$$T = (N/C) \cdot (A/a) \qquad (1)$$

Therefore, since T is minimum when $C \times a$ is maximum, it is desirable to obtain the largest possible value for $C \times a$ in the design of survey counters.

If the counting rate were simply proportional to the sensitive area, then the design for maximum sensitivity would coincide with that for minimum survey time, since it would be desirable to maximize C in both cases. However, it usually happens that any attempt to increase the sensitive area of scintillation counters is accompanied by a decrease in counting rate per unit sensitive area, so that the counting rate is not simply proportional to sensitive area. Consequently, both total counting rate and sensitive area must be considered in the design of survey counters.

When a photomultiplier views a flat, uniform, extended scintillation source, the pulses produced by scintillations

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from various points on the source vary in size. Consequently all elements of the source are not equally effective in producing counts. A definition of sensitive area, a, which will determine to what extent the less sensitive portions of the scintillation source may be used, is therefore necessary.

The sensitive area may be defined as that area by which the maximum counting rate per unit scintillation area must be multiplied to give the total counting rate. Then the contribution to the sensitive-area element, da, of an element of source area, dA, is

$$da = (\sigma/\sigma_0)dA \qquad (2)$$

where σ is the counting rate per unit area due to an element of scintillation source area; σ_0 is the counting rate per unit area due to the element of scintillation source area which produces the maximum counting rate. Hence the contribution of an element of area of the scintillation source to the sensitive area is proportional to its relative effectiveness in producing counts.

From Eq. 2,

$$a = \int da = \int \frac{\sigma}{\sigma_0} dA$$

$$= \frac{1}{\sigma_0} \int \sigma \, dA = \frac{C}{\sigma_0} \qquad (3)$$

where the integration is carried out over the entire scintillation area presented to the photomultiplier. It is the area defined by Eq. 3, rather than the total scintillation area, which is used in Eq. 1 to determine T. Thus, the evaluation of any attempted method of improving the performance of survey scintillation counters depends on the determination of the two quantities C and σ_0, whereas for fixed-detector applications only C must be determined.

Collection efficiency of cone. In Bell's attempt to increase the sensitive area of scintillation counters by optical methods, truncated cones "funneled" the light from scintillations at the base of the cone to the small end, where the photosensitive area of the photomultiplier was located. Geometrical considerations indicate that with such an arrangement the amount of light collected increases rapidly as the angle of the cone decreases.

For example, assuming isotropic radiation from a scintillation produced in the center of the base of a hollow, perfectly reflecting cone of the dimensions used by Bell, the amount of light striking the photosensitive area was about 7% of the total scintillation radiation. In comparison, the amount of light striking the photosensitive area in the case of a reflecting 6-in. cylinder of 3-in. diameter, is 25%, and, for a 140-degree truncated cone having the small, 3-in.-diameter end toward the scintillation source, is 17%. Thus, the most efficient collection of light occurs for cone angles near 0 degrees, that is, for nearly cylindrical shapes.

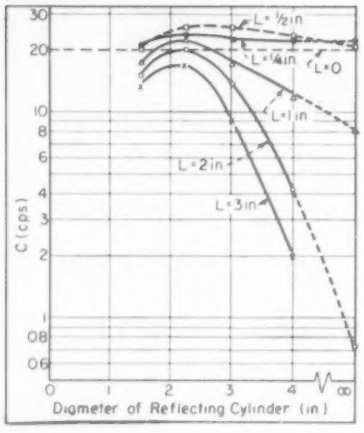

FIG. 1. Counting rate, C, as a function of reflecting-cylinder diameter for various cylinder lengths, L

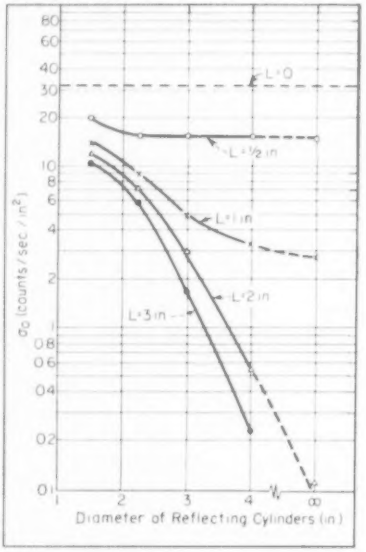

FIG. 2. Counting rate per unit scintillation-source area σ_0 producing maximum counting rate vs reflecting-cylinder diameter for various cylinder lengths

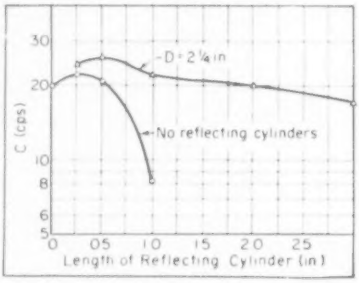

FIG. 3. Determination of cylinder length which gives, with optimum diameter (2.25 in.), maximum counting rate

Experimental Application

Various lengths and diameters of thin-walled glass tubing, wrapped in aluminum foil to provide a reflecting surface, were tested for possible improvement of the extended-source counting properties of a 1P21 photomultiplier tube. The scintillation source, distributed uniformly over a circular area of 5-in. diameter, consisted of a plutonium alpha-source undergoing approximately 5,700 disintegrations per second. The source was placed $\frac{1}{16}$ in. from a ZnS-Ag phosphor screen of approximately 10-mg/cm² thickness, which was deposited over the face of a Lucite disk 0.25 in. thick and 5 in. in diameter.

The scintillation source was placed at one end of each reflecting cylinder, and the 1P21 tube was placed at the other end. The photosensitive surface of the tube was centered on the axis of the cylinder. The 1P21 photomultiplier tube, the reflecting cylinder, and the scintillation source were placed in a light-tight box.

The photomultiplier voltage was supplied by a regulated, high-voltage power supply. The voltage was adjusted so that the discrimination level of the pulse was just above the dark-current pulses of the photomultiplier. The photomultiplier pulses were recorded on a standard laboratory scaler. Total counting rate, C, and the counting rate per unit area in the center of the scintillation source, σ_0, were determined. With these values, the sensitive area, a, and $C \times a$ were determined for each of the cylinders tested.

Results and Discussion

In Figs. 1 and 2, values are plotted for C and σ_0, respectively, as functions of the diameter of reflecting cylinders of various lengths. It can be seen that, because of decreased light-collecting efficiency, σ_0 decreases with in-

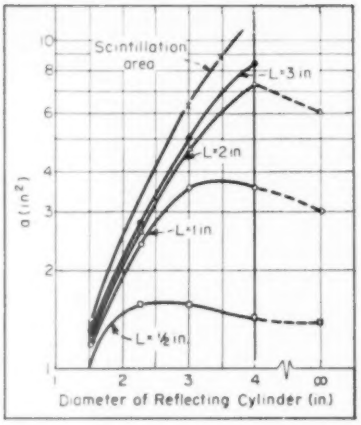

FIG. 4. Sensitive area, a, as a function of reflecting-cylinder diameter

creasing diameter of the reflecting cylinders for all lengths. However, the increase in scintillation area (the area of the scintillation source included within the reflecting cylinder), caused by increase of the diameter, initially compensates for the decreasing σ_0. As a result, the total counting rate increases. For each length there is a diameter beyond which further increase in scintillation area fails to compensate for the decreased σ_0, and consequently the total counting rate decreases.

The diameter at which the maximum counting rate occurs is about 2.25 in. for all lengths, and the length at which the maximum counting rate occurs is about 0.5 in. To determine this length more accurately and to compare its maximum with that obtained with no-reflecting cylinders, the value for C versus the length is plotted in Fig. 3 for cylinders of 2.25-in. diameter and for no-reflecting cylinders. The maximum counting rate which occurs for a reflecting cylinder 2.25 in. in diameter and 0.6 in. in length is 18% greater than that for no cylinders. The maximum counting rate for no-reflecting cylinder occurs at a distance of 0.3 in. from the photomultiplier.

Figure 4 shows the variation of the sensitive area, a, with the diameter and length of the reflecting cylinders. It is obtained by dividing the counting rate (Fig. 1) for a given diameter and length by the corresponding σ_0 (Fig. 2). The total scintillation area for various diameters is also shown in Fig. 4 for comparison with the sensitive area, a.

Figure 5 shows the dependence of the value $C \times a$ on the length and diameter of reflecting cylinders. Values were obtained by multiplying C (Fig. 1) for a given diameter and length by the corresponding sensitive area, a (Fig. 4). It is seen that the maximum $C \times a$ occurs for a diameter of 3 in. and a length of about 2 in. To determine this length more accurately, and to compare this maximum with that obtained with the case of no-reflecting cylinders, $C \times a$ versus length for 3-in. diameters and for no cylinders is plotted in Fig. 6. The maximum $C \times a$ occurs in the case of a reflecting cylinder of 3-in. diameter and 1.6-in. length and is 2.18 times greater than with no-reflecting cylinders.

To obtain the sensitive area for the dimensions of the reflecting cylinder which result in the maximum $C \times a$, the sensitive area versus cylinder length for a diameter of 3 in. is derived from Fig. 4. It is also seen from Fig. 6 that for the dimensions for maximum $C \times a$, the sensitive area is 4.4 in.², or 71% of the scintillation area.

Conclusions

With the arrangement and equipment used, the method of reflecting cylinders produces only about 20% improvement in the performance of the 1P21 photomultiplier tube in fixed-detector, extended-source counting applications. However, for survey applications, this method results in an approximately two-fold improvement of the extended-source counting properties of the 1P21 photomultiplier tube.

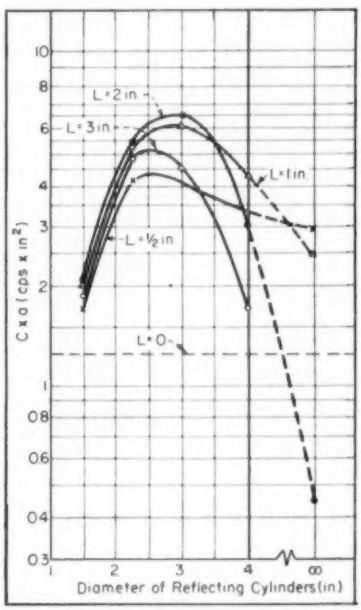

FIG. 5. Product of scintillation-area counting rate and sensitive area vs reflecting-cylinder diameter

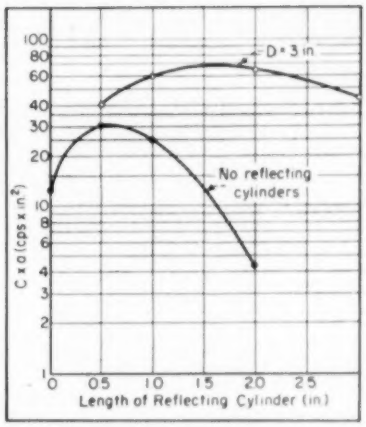

FIG. 6. Determination of length of 3-in.-diameter cylinder giving maximum $C \times a$

The specific results obtained in this experiment are greatly dependent upon the pulse-height distribution of the scintillation source, the type and sensitivity of the photomultiplier, and the discrimination level of the equipment used to record the photomultiplier pulse. One should not attempt to use the optimum design dimensions obtained in this experiment in the design of a particular scintillation counter, but should use as the design criterion the maximum value for sensitive area, C/σ_0, as obtained in Eq. 3, to determine the best design for a particular application.

In some applications, it might be desired to determine the best design subject to certain restrictions on the size of the optical arrangement. Design data such as that represented in Figs. 1, 2, 4, and 5 can be used to determine the best design consistent with such geometrical restrictions.

The same fundamental design principles apply, regardless of the particular optical system used. To improve the extended-source counting properties of a scintillation counter, effort should be made to maximize the counting rate, C, when greatest sensitivity is desired, and to maximize the value $C \times a$ (where $a = C/\sigma_0$, the sensitive area) for survey applications.

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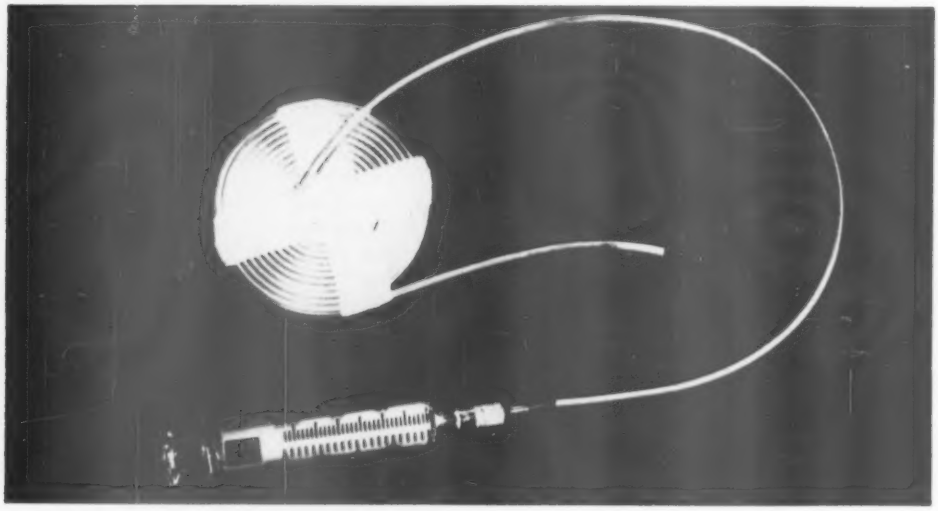

POLYETHYLENE tubing coiled to form container for liquid samples

A Method for Presenting Liquid Samples to the Flat Surface of a Scintillation Crystal

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In the course of plasma volume studies in this laboratory, it was necessary to measure the radioactivity of many liquid plasma samples containing albumin iodinated with I^{131}. A scintillation counter was used, and samples were presented to the flat face of a cylindrical thallium-activated sodium iodide crystal. The large number of samples made it necessary to reduce the time for each measurement to a minimum. Equal volumes had to be introduced to a container of fixed geometry without the labor of measuring the volume of each one. Of course, this container had to be easily cleaned between samples.

A flat coil of polyethylene tubing was made, as shown in the photograph, and simply attached to the sensitive face of the crystal with adhesive tape. The coil was wound of polyethylene tubing which was 0.023 inches inner diameter and 0.038 inches outer diameter (Clay Adams PE50), held together with short strips of adhesive tape. The coil shown in the photograph has an outer diameter of 2 in. and a volume of 0.50 cm^3 in 16 turns of size PE50 tubing.

These coils are most easily wound as follows: Cut off a length of $\frac{1}{4}$-in. wide adhesive tape equal to the diameter of the sensitive area of the crystal. Lay it on a flat surface, sticky side up. Five inches from the end of a 6-ft length of the tubing, form a loop with the same diameter as the sensitive area of the crystal. Then press the loop against the adhesive tape, thus holding it firmly. Wind succeeding loops inside this, so that there is no wasted space between them. Hold the loops together by pressing them against the adhesive tape.

As the center is approached, and the radii of the loops become smaller, a point will be reached where the tubing kinks instead of coiling smoothly. The winding is stopped at this point and the last turn is firmly fixed by a strip of adhesive tape placed on the opposite side of the coil from the first strip. The volume is now measured by inserting water with a syringe and needle. A 21-gage needle just fits this tubing. Adjust to the desired volume by removing turns from the periphery of the coil. The coil can now be handled and may be further strengthened with adhesive strips wherever the loops show signs of separating.

By using tubing with larger inner diameter, the coil would have contained a larger volume. The number of turns could be increased also, but the outer part of the coil should not extend beyond the edge of the crystal because the radioactivity in this part would not be measured.

The two uncoiled ends of the tubing serve as input and exhaust tubes. The crystal and associated phototube used here were built into a horizontal lead shield made by Technical Associates. A triode-connected 6AU6 cathode follower was built on a shelf attached to the rear of the shield. The input and exhaust ends of the tubing were let out through a crack in the door.

Light was prevented from leaking in through this crack by foam-rubber strips which were attached to the lead shield with electricians friction tape. In a fresh state the tape is sticky on both sides. If one side is pressed against the lead shield, and small foam rubber strips ($3 \times \frac{1}{2} \times \frac{1}{8}$ in. thick) are pressed firmly against the other side, it will be possible to open and close the door without dislodging the foam rubber.

Samples from 2-cm³ syringes were introduced through a 21-gage needle permanently fitted into the end of one of the tubes. It was found that the remains of the previous sample left in the tubing could change the counting rate as much as 20%. To avoid this, a volume of sample was run through equal to twice the volume of the coil. Thus the first part of the sample acted as a rinse to remove the previous sample and ran out the exhaust tube and was wasted. The remainder which filled the coil was undiluted; this is the solution that was counted. No significant change in counting rate was observed when the coil was filled a third and fourth time with the same sample, indicating that these parts were undiluted by the previous sample.

Various methods of washing the radioactive plasma out of the tubing were tried. The best cleaning solution was 10 gm of detergent (Alconex) in a liter of water. When 10 cm³ of this solution was run through the coil shown in the photograph, the counting rate was reduced from 5,000 cpm to the background level of 107 cpm.

Conclusions

The advantages of this device are:

1. Counting geometry is fixed. Sample volumes are identical without careful measuring.

2. The light-tight counter chamber does not have to be opened and high voltage removed (to prevent damage to the photomultiplier) each time a sample is changed.

3. The coil is easily built.

4. A wide variety of solutions may be measured since the makers claim that polyethylene is unreactive at room temperature with strong acids or bases.

5. Easy washing with large volumes of solution is possible due to the continuous flow provided.

6. The volumes presented to the counter can be easily changed by winding a new coil.

A Comment on Naturally Radioactive Commercial Glazes

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W. H. Hoather* has recently reported that radioactive building tiles were found at the Derbyshire Royal Infirmary in amounts sufficient to produce serious elevations of the background count. The purpose of this note is to point out that this hazard is not limited to tile produced in England, but is present in tile produced in large quantities in the United States.

Some time ago a routine monitoring here over an area used for intraperitoneal infusion of colloidal Au^{198} showed an extremely high background, subsequently traceable to the grey ceramic wall tile of the room. These glazed tiles were $4\frac{1}{4} \times 4\frac{1}{4} \times \frac{1}{4}$ in. The glazed surface which gave the tile its color was about $\frac{1}{32}$ in. thick.

In a small room 129 cm wide, 286 cm long, and 300 centimeters high, with the wall tile extending from the floor to 179 cm high on all four walls, the count at the center of the room and 100 cm from the floor (the tube pointing at the wall) was 350 cpm or about 10 times normal background count. (All monitoring was done with a T.G.C.#1, mica end-window G-M tube.) At 40 cm from the wall the count was 400 cpm; at 20 cm it was 500 cpm; at contact between tube and wall the individual tile count varied from 600 to 1,050 cpm. With the monitoring Geiger tube placed in the adjoining room and positioned horizontally looking towards the open doorway of the tiled room, one meter away, the count was raised to twice the normal background.

A large number of tiles from the same manufacturing source were tested. Contact activities were found all the way from normal background to values 30 times background count. Each tile showed some variation in activity from point to point on its surface. Activities were found in tiles of several colors and shades.

The glaze in the case of the grey tile used a "small percentage" (manufacturer's quantitation) of sodium uranate ("yellow uranium") composed of Na_2UO_4. When fired, this reduces to 75 to 80% U_3O_8. This uranium oxide presumably is the source of the radiation from the tile. X-ray diffraction analysis showed the glaze on the hottest grey tile to be primarily willemite. This tile also showed characteristic fluorescence under the X-ray beam.

All of the activity remains in the glaze as evidenced by a contact count of 1,100 cpm on the glaze side as against a normal background of 35 cpm on the tile backs. Since the glass-like glaze fortunately is difficult to remove, the danger of contamination by dusting is remote. In addition, since the radiation is primarily particulate, it is possible to work with low backgrounds in rooms adjoining such tile installations because of the shielding produced by door and wall. In concurrence with W. H. Hoather, no health physics problem was encountered here with installed tile. However, it was found that this type of wall cover is frequently fitted and squared by grinding off one edge with a high-speed wheel. Here, health physics dictates the use of aspirators and other techniques to avoid spread and ingestion of the dust.

The greatest difficulty occurs where such innocent appearing tile installations are not recognized as possible carriers of radioactive elements, and large errors are introduced into otherwise accurate counting techniques. Tile is occasionally recommended for special laboratory use, and installations are frequently seen in counting rooms.

The manufacturer of the grey tile discussed here has discontinued manufacture of uranium glazes. However, this does not preclude the presence of these tiles in new installations.

* Nucleonics **10**, No. 12, 73 (1952).

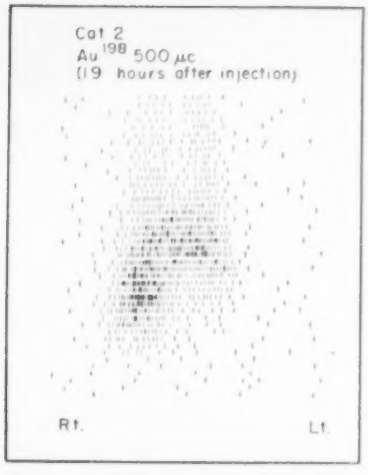

FIG. 1. Hepatic scintigram obtained one hour after injection. Note the liver outline

FIG. 2. Effect of dose on scintigrams is shown by scintigrams obtained with 2 : 1 dose ratio

Use of Colloidal Au^{198} for Obtaining Scintigrams of the Liver

By ERIC T. YUHL,* LLOYD A. STIRRETT, and BENEDICT CASSEN

Surgical Service and Radioisotope Unit, Veterans Administration Center and Departments of Surgery and Biophysics, School of Medicine, University of California at Los Angeles Los Angeles, California

The success of the scintigraphic technique (*1*) for recording the anatomic configuration of the thyroid gland has stimulated the investigation of the possible application of the scintiscanner to other diagnostic purposes. One application currently being studied is the introduction of suitable gamma-emitting tracer agents into the spinal fluid. Bauer and Yuhl (*2*) described a technique of introducing iodinated human serum albumin into the spinal subarachnoid space. This procedure has been termed "myeloscintography."

Yuhl, Stirrett, Hill and Beal (*3*) have also described the use of radioiodinated compounds and the scintiscanner to outline the gall bladder. Preliminary results in obtaining scintigrams of the gall bladder have been successful, and the term "cholescintigram" has been applied to the procedure.

The present report is concerned with the description of an experimental method of obtaining scintigrams of the liver. That such a method might be feasible was suggested by investigations (*4, 5*) which demonstrated that 80 to 90% of colloidal gold introduced into the circulation was picked up by the von Kupffer cells of the liver. The preliminary experiments described herein were undertaken to determine if the affinity of the reticulo-endothelial cells of the liver for particulate or colloidal matter—in this case colloidal gold—was sufficiently specific to make it possible to obtain an outline of the liver in experimental animals by use of a scintillation scanning device.

Procedure

The radioactive gold used in this study was prepared as a sterile colloidal solution† suitable for intravenous use. Gold has a 0.41-Mev gamma ray and a half-life of 2.69 days.

The experimental animals (cats and rabbits) were anesthetized with Nembutal, and a single intravenous injection of radiogold was administered to each. The scintiscanner (*6*) was used to record the distribution of the Au^{198}. The counter was set to scan the entire thorax and abdomen after placing the animal in a supine position. Scanning was begun immediately after the injection. The scanning speed and counting rate were set to obtain the maximum contrast between the liver and body background.

Following completion of the survey, the exact location of the xiphoid process and costal margins were marked upon the scintigram for the purpose of anatomic orientation. A subsequent radiograph of the abdomen was obtained to orient clearly the anatomic location of the observed distribution of radioactivity. Surveys were then repeated at various intervals after injection to observe the disappearance rate and any variation in the distribution pattern of the tracer agent.

Each of the animals was sacrificed at a different interval after injection (1 to 14 days), and the size and configuration of the liver was determined.

Results

Hepatic scintigrams have been obtained in four cats and two rabbits. Doses of Au^{198} varying from 10 micro-

* Research Fellow, U. S. Public Health Service, National Institute of Neurological Diseases and Blindness.

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curies per kilogram of body weight to 100 μc/kg were used, and it was observed that at least 25 μc/kg were necessary to obtain a satisfactory outline of the liver when using the present instrumentation. As the dose was increased above this figure, the delineation of the liver became increasingly sharp. Figures 1 and 2 illustrate the radioactivity distribution patterns observed in two cats and show the increased clearness of the liver outline as the total dosage was increased from 250 to 500 μc.

The radiogold appeared in the liver area within one to two minutes after injection and reached its maximum concentration one hour thereafter. The major portion of the radioactivity was observed to be concentrated in the liver area; the remainder appeared in the lungs. Presumably the latter concentration was due to the rich distribution of reticulo-endothelial cells in the lungs. There was no significant activity detected over the spleen or the remainder of the reticulo-endothelial system. Surveys taken at intervals of 20, 48, 72 and 96 hours after injection revealed no variation in the distribution pattern of the radiogold in the experimental animals.

Comparison of the liver *in vitro* and the radioactivity pattern observed on the scintigram revealed close anatomic correlation in each instance. Serial sections of the liver were made and stained with hematoxylin-eosin. In all of the sections, microscopic examination revealed normal hepatic tissue.

Discussion

The observations on the experimental animals indicate that visual delineation of the liver *in vivo* is feasible. Despite the short half-life of Au^{198} this agent is suitable for use in obtaining scintigrams of the liver because the isotope is taken up rapidly and in high concentration by the liver. Satisfactory scintigrams of the liver may be obtained as long as 72 hours after intravenous administration of radiogold, because of the high specific activity in the liver area.

In previous publications (*7, 8*) the authors have described the use of iodinated human serum albumin and the scintillation counter for the diagnosis of hepatic neoplasms. The application of this technique to human beings for diagnostic purposes cannot be attempted at the present time, however, because of the high dose of radiogold required to obtain a hepatic scintigram under the conditions of this experiment. However, instrumentation developments are currently in progress at this laboratory in an effort to determine if such instrumentation would permit employing a dose of radioactive colloidal gold which would be fully within the limits of safety for application to human beings.

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Care of Radium Salts

By S. C. LIND

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When radium is used as a quantitative source of radiation either for scientific or therapeutic purposes, it is necessary to seal one of its salts hermetically in a suitable container to conserve the gaseous radon which together with its decay products furnishes most of the radiation. No leakage of radon is permissible. Not only would radiation be lost, but active deposit would cause external contamination.

Early experience showed that ordinary soft soda-lime glass is reliable as container. The International Radium Standards, as well as the much larger secondary standards prepared by Hönigschmid in Vienna, and the U. S. Bureau of Mines chlorides (1, 10, 60 and 140 mg of Ra), sealed in soft glass tubes, have remained intact for more than forty years. The largest Vienna standard containing over 600 mg of Ra was recently opened for fear the accumulated helium might cause rupture. It has long been known that Pyrex glass and fused quartz develop cracks under alpha-ray bombardment and cannot be used as radium containers.

A further precaution was often used in glass containers by sealing in a small platinum wire to conduct away unipolar charge and thus avoid the danger of sparking through the glass wall. Experience has shown that this is unnecessary.* In sealing large quantities of radon in very small thin bulbs (so-called alpha-ray bulbs) a metallic conductor is probably desirable as there have been a few cases of rupture in the absence of a conductor where sparking under the conditions of high intensity of radiation in the thin-wall vessel was suspected.

* In a private communication, Dr. V. F. Hess of Fordham University, who had long experience with the Vienna Standards, shares this opinion.

Metal Containers

The use of metal needles containing $RaSO_4$ was first introduced by radiologists in radiation therapy. Several advantages were sought. Heavy metal or alloys such as gold or platinum or platinum-iridium alloy screen out unwanted beta but transmit gamma rays. The metal provides a more rugged container for clinical use, and needles could be conveniently inserted and withdrawn from tissue.

Subsequently, radium producers, abandoning entirely the use of glass, extended the employment of metal to larger capsules of Pt-Ir, Monel or even brass, containing large quantities of radium. Hermetical sealing is effected by caps or plugs of the same metal as the container, bound to it by gold, silver or base-metal solder. The resulting bond, satisfactory at first, appears to deteriorate with time until a leak of radon occurs. This is serious enough in itself and requires resoldering or other repair operations, if not retubing of the salt. But a more serious accident sometimes results in the case of capsules fitted with a friction plug without threads. The internal accumulation of gas may give rise to pressure sufficient to blow out the plug and scatter the salts widely, producing high contamination in the immediate surroundings or in an entire building, especially if a ventilating system is in

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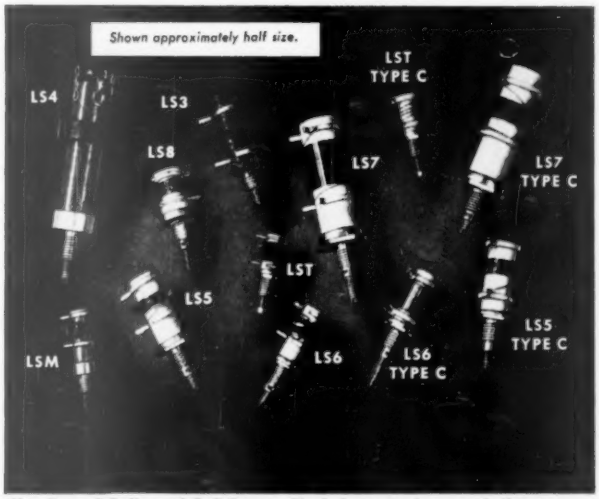

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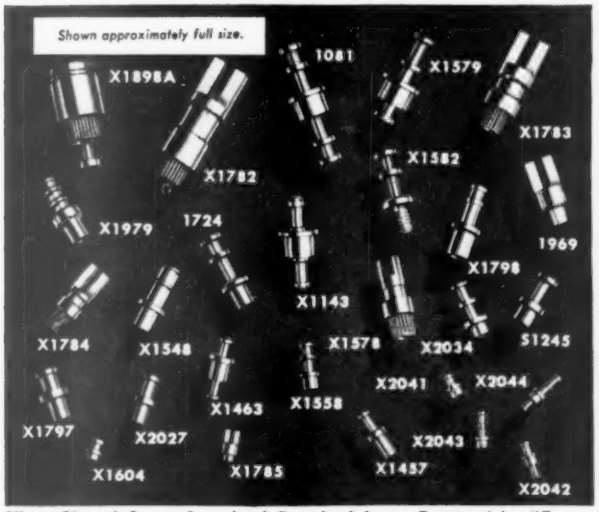

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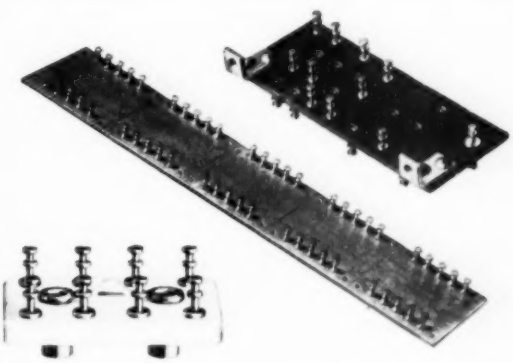

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operation. The internal pressure may be due to two causes:

1. The inevitable accumulation of helium (fossil alpha particles) which, increasing in direct proportion to the age of the source and to the quantity of radium, may in time produce excessive pressure of helium dependent on the free gas space. Under ordinary conditions the helium pressure should not become hazardous for many years and can be accurately calculated at any time from the age and the free gas volume.

2. A more potent source of internal pressure develops when the radium salt has not been thoroughly dehydrated before sealing. Any moisture would be rapidly decomposed by alpha rays to gaseous hydrogen (and oxygen) in large volume, though the oxygen may combine with the salt and remain in the solid state. If the moisture content is large, very high pressure will be produced in relatively short time. The ultimate pressure from this cause will be independent of the quantity of radium.

Adequate dehydration of radium salts, including that of the chloride and bromide, both of which have water of crystallization, is so easily accomplished that imperfect drying represents inexcusable negligence on the part of the producer. Drying at 250–300° C for a half hour has proved sufficient for the hydrated chloride or bromide ($RaCl_2 \cdot 2H_2O$; $RaBr_2 \cdot 2H_2O$); $RaSO_4$ presents even less difficulty since it has no water of crystallization.

Nevertheless, evidence is accumulating that there has been some carelessness in the drying of radium salts before tubing for sale. In the past few years there have been several accidents where radium capsules have ruptured by pressure hardly accountable by accumulation of helium over short periods of time (a few years).

When a radium capsule having excess internal gas pressure is subjected to mechanical stress or to temperatures above ordinary, the danger of rupture is greatly enhanced and may occur suddenly with ejection of the friction plug and of part or all of the contents of the capsule (*1*). Such cases of serious contamination bring one to consider the "air lift" method of handling radium capsules.

"Air Lift" Method

When radium is employed for calibration where a time factor of dosage is involved, the times of exposure are sometimes so short that it is desirable to begin and end the exposure by some very quick and definite procedure. Consequently, the air lift method of bringing the radium capsule into the desired position was devised as described (*2*) for the calibration of photographic films used as dosimeters for the protection of personnel. This easy and cheap method of moving the capsules rapidly by air blast in a vertical plastic tube of diameter slightly greater than the capsule was soon adopted at many installations and applied to quantities of radium from a few to 480 mg.

The air lift method was satisfactory for a time but later began to cause serious "spills" with resulting contamination (*3*). Within the past two years there have been at least three such accidents in the U. S.—all with distressing results. The loss of radium is the least disaster. A quantity of a few milligrams can cause damage and costs of decontamination several hundred times the value of the radium involved. No better method of spreading radioactive contamination could be conceived than an air blast acting on a ruptured capsule, where the salt content is suddenly ejected by the accumulated internal gas pressure and carried into the general ventillating system of a laboratory or entire building, which then is closed for the protection of personnel and subjected to a decontamination operation that may take weeks or months. Indeed, on account of the extreme sensitivity of modern counting, it may be impossible in such areas ever to carry out measurements requiring the lowest possible background of radiation.

Causes and Remedies

One must inquire as to the causes of this outburst of radium spills and suggest remedies. Bearing in mind the long successful history of glass containers of *dry* salts, one must prefer soft glass as primary container and raise the following questions regarding metal:

1. The dryness of the radium salts. The remedy already suggested is simple and inexpensive.

2. The long-time integrity of soldered metal bonding. The fact that these bonds remain tight for a time and then begin to leak suggest an *aging* effect, possibly due to radiation damage of the metal bond. The remedy is an inner tube of soda-lime glass, or, for metal capsules, the "cell-filled" type container which simply means two containers, an inner and outer one. The outer metal should have a threaded cap. If Lucite or other plastic is used for the outer, it will be chemically attacked and embrittled in time by gamma radiation. If the Ra salt is already in metal, an aluminum outer jacket with screw cap should be added, followed by recalibration. For new preparations, an inner thin glass tube is recommended contained in a metal capsule with threaded cap.

3. The ability of present type bonded metal containers to withstand the mechanical impact of the air lift technique. Such containers with excess gas pressure and bonding damaged by radiation will, under repeated impact, surely lead to rupture or leak sooner or later. The best remedy is to abandon the air-blast method, keeping the source stationary, and moving mechanically either a shield or the objects being calibrated. If the air blast is to be used at all, it should be restricted to "cell-filled" containers and a mild type of blast or preferably vacuum exhaust.

All metal containers should be examined for radon leaks at frequent intervals—the older the more frequently. This is certainly a case of "a stitch in time." A simple procedure is to keep a small quantity of cotton stored with the source. By removing the cotton periodically, a leak is detected by the radiation from active deposit.

In procuring radium, the following specifications should be made and met:

1. Inner container, soft soda-lime glass, sealed tube of known weight, length, internal diameter, volume, and wall thickness.

2. If insoluble salt, dry $RaSO_4$ with known content of $BaSO_4$.

3. If soluble salt, dry $RaCl_2$ with known content of $BaCl_2$. $RaBr_2$ is less stable under radiation and is not recommended.

4. A Ra-Be neutron source is usually prepared by mixing $RaCl_2$ (or $RaBr_2$) in solution with finely divided Be, dried and compressed into a cylindrical metal container. Since soldering is required, the source should be inspected periodically for radon leak.

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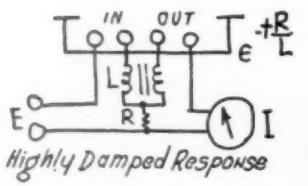

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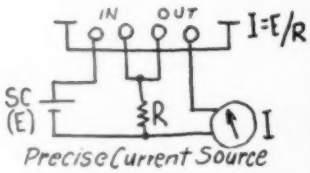

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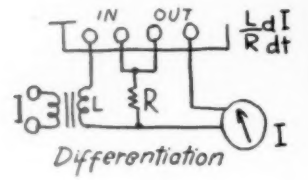

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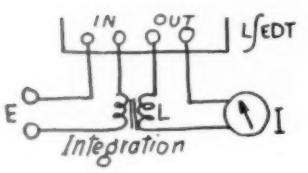

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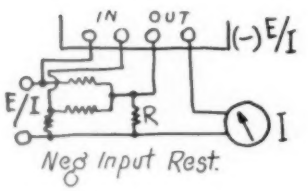

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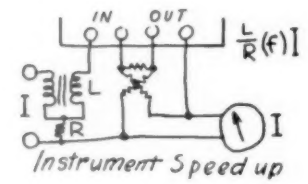

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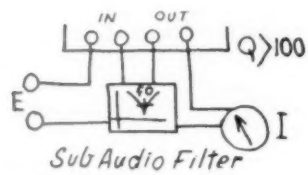

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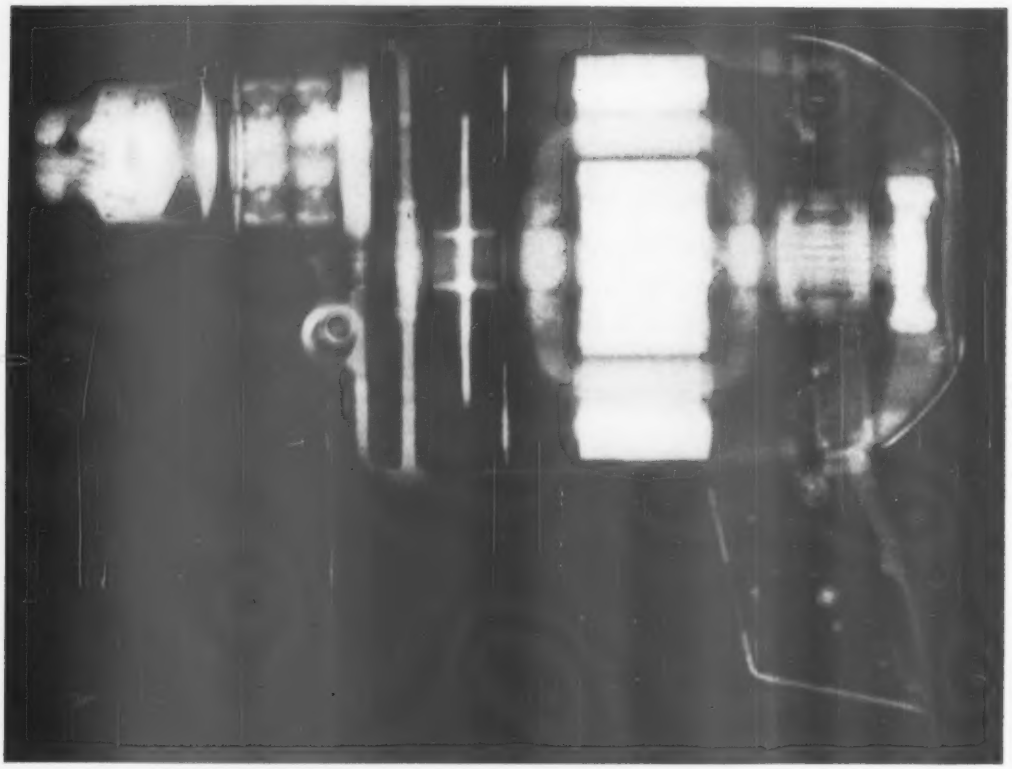

CESIUM-137 was used as a gamma source to obtain this radiograph of a pistol-grip electric drill at the Atomic Energy Research Establishment, Harwell, England. W. S. Eastwood used Industrial B film with lead screens with a 30 inch source to film distance. The source, 50 millicuries of cesium-137, was a cylinder 4 mm in diameter and 4 mm high; it was prepared by the Radiochemical Center, Amersham, England

Power-only Reactors, by G. L. Weil *(Continued from p. 15)*

nuclear power will be competitive in these countries at a much earlier date.

It is not out of the question that nuclear power, if it were available today, could compete in certain foreign areas.

This possibility opens up immediate economic uses for nuclear power which might well be of interest to this country's Point Four programs in underdeveloped areas. It is hard to conceive that any other type than a power-only plant would be adaptable for use at these locations. For this reason, the single-purpose approach offers the opportunity of developing directly a prototype plant which might be technically and economically suited to immediate application if other factors, such as the international situation and governmental policies, were propitious.

Conclusion

The case for the single-purpose plant has necessarily been formulated in considerable part as a case against the dual-purpose plant since the latter has so far been the principal subject of public attention. The single-purpose plant should be recognized as the primary, direct approach to the development of industrial nuclear power, and the dual-purpose plant as the secondary alternative.

The potential industrial market for nuclear power in the immediate future may be preponderantly outside the boundaries of the U. S., and our interests would therefore be associated with Point Four and Mutual Security objectives; power-only plants would be most suitable for these applications if they materialized. Similarly, in the long run, any significant contribution of nuclear power to the industrial requirements of the United States will be supplied by power-only plants.

The dual-purpose approach represents an attempt to modify the single-purpose approach to make it more palatable at this time. But by so doing, it is maintained, the immediate needs of a program to develop industrial use of nuclear power are obscured by the overwhelming military importance and value attached to plutonium.

The construction now of a dual-purpose plant would not eliminate the need for a single-purpose plant. Only a single-purpose plant can produce useful data on nuclear power cost.

If the financing of a power-only plant can be arranged at this time, then the dual-purpose approach loses its significance as a step in the development of industrial nuclear power.

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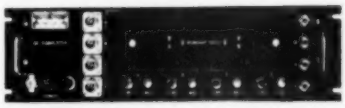

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BOOKS

Modern Radiochemical Practice

By G. B. COOK and J. F. DUNCAN, Oxford University Press, London, 1952, xx + 407 pages, $8.50. Reviewed by CHARLES ROSENBLUM, Merck & Co., Inc., Rahway, N. J.

The last few years have witnessed the publication of a number of excellent books dealing with the properties of radioisotopes and their applications. Believing that the practical aspects of radioactivity measurements have been less fully presented than its theoretical aspects, the authors set out to fill this gap in a volume "intended primarily for chemists and others who have received rudimentary instruction in radioactivity in their degree course, and who wish to learn radiotracer methods. . ." Although the reviewer does not agree that the gap is quite as wide as suggested, Messrs. Cook and Duncan, have written an excellent book which will be extremely useful to an individual actively engaged in, or contemplating, tracer studies with radioisotopes, be he chemist, biologist or engineer.

The book is composed of seven chapters, a section on suggested experiments with radioactive material, in which thirty laboratory exercises are described, and a table of isotopes and their properties essentially complete up to July, 1950.

Chapter I (41 pp) is a brief survey of radiochemical separation and isotope applications. Chapter II (73 pp) contains a comprehensive discussion of the laws governing radioactive decay and the types of radiations emitted by radioactive materials, together with methods of measuring half-lives and radiation energies. The next two chapters, Chapters III (53 pp) and IV (23 pp), are devoted to the basic principles and operation of conventional devices, including auxiliary electronic equipment, for measuring alpha, beta, and gamma radiation and neutrons. The tabulation of common faults of Geiger tubes and auxiliary equipment, together with symptoms, tests, and possible remedies, is a feature which will be of great service to an investigator. In Chapter V (35 pp) on radioisotope production, the activation of elements and secondary reactions such as the Szilard-Chalmers effect, which occur during the neutron irradiation of compounds, are given special attention. Chapter VI (38 pp) on counting errors in the measurement of solid, liquid and gaseous samples is an outstanding discussion of the subject. The last chapter, VII (20 pp), deals with the potential hazards from radioactive materials, detection of contamination, and protective measures to be employed.

The section containing suggested experiments (67 pp) is, in effect, a laboratory course in radiochemistry at the millicurie level or below. Combined with the excellent presentation of the practical aspects of radioactivity and measurement of radiations, this book would serve admirably as a text for such a course. Material is well organized and clearly presented. The text is very readable, and should lend itself readily to instructional purposes.

The typography is excellent. The authors have provided many helpful figures and diagrams to illustrate their points; and the abundant documentation should enhance the value of the book as a reference work.

It is regrettable that autoradiography was not given more attention in a book of this scope. Although a laboratory exercise is included among the suggested experiments, a technique so widely employed in chemical and biological work could well be elaborated in a major work on practical radiochemistry. Nevertheless the reviewer does not hesitate to recommend this book to workers in this field of radiochemistry, and is pleased to have a copy for his own reference.

Elements of Wave Mechanics

By N. F. MOTT (Cambridge University Press, New York, 1952, ix + 156 pages, $3.75). Reviewed by JOHN C. SLATER, Department of Physics, Massachusetts Institute of Technology, Cambridge, Mass.

This is an attractive little book. A reader who, like the present reviewer, is familiar with practically everything in it before he reads it, can go through it with pleasure and profit in an evening. Very superficially we can indicate its scope by the chapter headings: *The Differential Equations of Wave Mechanics; The Wave Equation of Schrödinger, Wave Groups and the Uncertainty Principle, Stationary States, The Many-Body Problem, Transition Probabilities,* and *Relativistic and Nuclear Developments.* It contains a surprisingly large

amount of information for a book so small. It has a considerable number of good problems.

But in spite of these commendatory remarks, the reviewer must admit that he spent most of his time, while reading it, in trying to figure out what class of reader would really want to use such a book. The writer attempts to answer this question in his preface, so short that it can be quoted in its entirety: "This book is written to replace the author's 'An Outline of Wave Mechanics' (1930). It is intended for students in the final year of an honors course of experimental physics, and also as an introduction to more advanced text-books for those who intend to specialize in the subject. With such readers in view, and in order to keep the book reasonably short, the author has chosen to omit mathematical development that can easily be found elsewhere. This book builds up the elementary theory from experimental facts, and shows how simple problems can be solved. A number of examples are included."

The reviewer does not know anything about the attainments of British students in the final year of an honors course of experimental physics; but he does not recognize any stage in the training of American students which can correspond very closely, for he does not see any stage of their training in which a book of this type would seem to be the correct sort. The reason is clear from the first sentences of this review: the book is useful for one who knows everything in it before he starts to read it, but its value is very doubtful for one without previous knowledge of wave mechanics.

The density of equations is high, a good many per page. But the density of real derivations is very low; all too often the reader is told that "it can be shown" or "the derivation will be found in any text on quantum theory" or on spherical harmonics or whatever it may be. The reviewer is not a believer in throwing sketchy derivations at a reader, which he would have to spend hours either in working out properly for himself or in looking up in another book. Of course, the author's purpose may have been to encourage just such independent work, but this seems to the reviewer a more appropriate function for the problems than for the text of a book.

Why, for instance, should there be a long but sketchy mathematical treatment of the excitation of an atom by a

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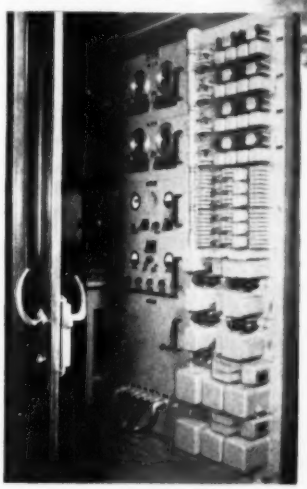

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passing proton, or of the Auger effect, in a book which devotes only six pages to nonhydrogenic atoms, six to the theory of solids, and six to nuclear physics, and which regards Green's theorem, the nature of spherical harmonics, and the exact solutions of the Schrödinger equations for the linear oscillator and the hydrogen atom, as being beyond its scope?

From the point of view of the American reader, in other words, the emphasis and scope of the book seem peculiar. This does not alter the fact that it is a pleasant presentation for someone who already knows the subject well enough so that he can mentally fill in the gaps.

BOOKS RECEIVED

Applied Inorganic Analysis by W. F. Hillebrand and G. E. F. Lundell (2nd edition) revised by G. E. F. Lundell, H. A. Bright, and J. I. Hoffman, John Wiley & Sons, Inc., New York, 1953, xxii + 1034 pages, $15. (*To be reviewed.*)

Pile Neutron Research by Donald J. Hughes, Addison-Wesley Publishing Co., Inc., Cambridge, Mass., 1953, xiii + 386 pages, $8.50. (*To be reviewed.*)

Atomic Energy Industrial and Legal Problems, University of Michigan Press, Ann Arbor, Mich., 1952, vi + 280 pages, $5.00.

This is the text of lectures and panel discussions delivered at the Fifth Summer Institute of the University of Michigan Law School, June 26–28, 1952, by key men in the atomic-energy field familiar with these problems. They covered the subjects of the potential use of atomic energy by private enterprise, private capital for nuclear power, the Canadian atomic energy program, labor-management relations in atomic energy affairs, the AEC contractor and supplier, government policies affecting private enterprise, radiation hazards to life and property, and the work of both the University of Michigan Phoenix Program and the Joint Congressional Committee on Atomic Energy.

The Composition and Assaying of Minerals, by John Stewart-Remington and Wilfrid Francis, Philosophical Library, Inc., New York, 1953, viii + 127 pages, $5.50.

A guide to the qualitative and quantitative examination of minerals, for use by geologists, minerologists, metallurgists, chemists, and students who lack access to large-laboratory instruments such as the spectrograph.

The Atom Story, by J. G. Feinberg, Philosophical Library, Inc., New York, 1953, viii + 243 pages, $4.75.

A subtitle explains that this is "the story of the atom and the human race." In a foreword, F. Soddy endorses the author's belief that an understanding of no other subject is of greater importance to the ordinary man at the present time. It is a well-told story, with each chapter almost a short story in itself. It is developed chronologically and substantiated entertainingly by carefully chosen excerpts from the literature of the times (viz., scientific papers, ditties hinting of the naughty roentgen ray, etc.).

The Radiant Universe, by George W. Hill, Philosophical Library, New York, 1952, 489 pages, $4.75.

Basing his theory on the hypothesis that a "form of radiation, (energy propagation), is a reality throughout all space whether such space is occupied by matter or not," the author develops his viewpoints on a radiant universe in six sections entitled *Radiation, The Stars, Origins in the Solar System, Origins in the Earth, Galactic Systems,* and *Gravitation.*

ALSO OF NOTE

Federal Civil Defense Administration Annual Report for 1952. The progress made toward national civil defense during the past year is summarized in 138 pages, which also include a cumulative account of FCDA work in general. A section on radiological defense lists eight publications available on the subject and discusses briefly progress with radiac instrument development. *GPO, Washington 25, D. C., $0.40.*

Bibliography on Industrial Radiology 1950–1952 (price $2) and **Bibliography on X-ray Stress Analysis, 2nd ed.,** (price $4) both by Herbert R. Isenburger have just been published and are available from *St. John X-Ray Laboratory, Califon, N. J.*

Liquid Metals Handbook (2d ed., June 1952), Richard N. Lyon, editor-in-chief. Many new diagrams and data have been added to this publication, the first revision made since its appearance in June, 1950. The major

changes occur in the chapters on physical properties, chemical properties, corrosion, and equipment associated with liquid metals. Published cooperatively by the Atomic Energy Commission and the Dept. of the Navy, the book contains 269 pages. *GPO, Washington 25, D. C., $1.*

Use of Radioactive Material to Measure Soil Moisture and Density, by D. J. Belcher, R. C. Herner, T. R. Cuykendall, and H. S. Sack. **Radioisotopes and Nuclear Reactors Applied to Soil Mechanics Problems,** by H. E. Hosticka. **Determining Soil Moisture and Density by Nuclear Radiations,** by D. A. Lane, B. B. Torchinsky, and J. W. T. Spinks. These three papers, published under a single cover, were read at an ASTM symposium on radioisotopes in soil mechanics in March, 1952. *American Society for Testing Materials, 1916 Race St., Philadelphia, Pa., $1.25 ($0.95 to members).*

An Annotated Bibliography of Selected References on the Solid-State Reactions of the Uranium Oxides (NBS Circular 535), by S. M. Lang. A listing of 257 references according to subject and author on solid-state reactions of UO_2 with 36 other oxides. This publication resulted from a study being made by the National Bureau of Standards in connection with possible use of ceramics, especially high melting-point metallic oxides, as structural and fuel elements for nuclear reactors. *GPO, Washington 25, D. C., $0.30.*

The National Research Council Review, 1952 (NRC No. 2852). Thirty-two pages of this 271-page report are devoted to a review of the work of the Canadian atomic energy project at Chalk River, Ont. *Publications Branch, National Research Council, Ottawa, Canada, $0.75.*

Ferroelectricity, by E. T. Jaynes (1953). The first of a series of publications called "Investigations in Physics," edited by Eugene Wigner and Robert Hofstadter, this offset, paper-bound book is an extensive revision of a doctoral thesis written in 1950. It is a general introduction to the subject of ferroelectricity, a guide to the literature, and a review of various theories of $BaTiO_3$. The electronic theory developed by the author is treated in more detail than the rest. Other topics include thermodynamic treatment, internal fields in crystals, and electric polarization in crystals, *Princeton Univ. Press, Princeton, N. J., $2.*

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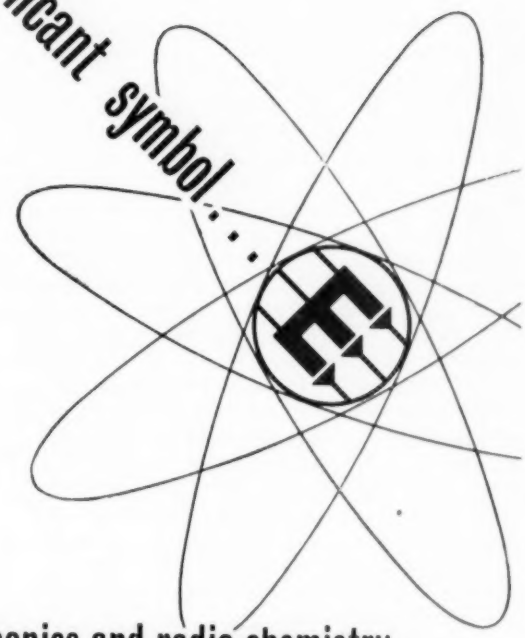

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NUCLEONIC EVENTS

Joint Congressional Committee Begins Hearings on Possibilities of Private Nuclear Power Development

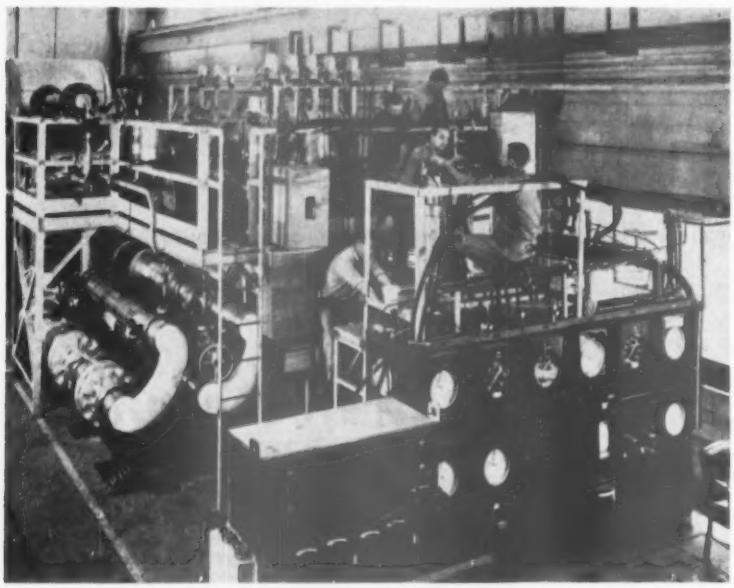
Congressional hearings on reactor development, including discussion of the possibilities of commercial power production, have been started by a subcommittee of the Joint Committee on Atomic Energy. The plan is to start with Atomic Energy Commission and Department of Defense testimony and then to bring in private groups interested in the development of nuclear power.

According to Representative Carl T. Durham (D., N. C.), acting chairman of the committee, the group is taking up its review of nuclear power potentialities about where it left off in hearings last autumn. Those hearings were held behind closed doors.

The subcommittee has had off-the-record talks with AEC representatives. Portions of the hearings will probably be closed—such as testimony on stockpiles and stockpile goals. The effects on this stockpile of an extensive program of nuclear power development could form a significant part of the testimony by AEC and Department of Defense representatives.

It appears that a major objective of the present hearings is to help the committee decide whether or not it should take steps this year to amend the Atomic Energy Act of 1946 to permit further participation by private enterprise in the development of nuclear power. The provisions of the act that are considered the greatest hindrance to the private development of nuclear power are those that forbid ownership of fissionable materials and reactors by private sources.

Durham, who was still acting head of the committee because of the deadlock over naming a Republican chairman (NU, March '53, p. 70), took unprecedented steps to resume the hearings. He named a subcommittee, headed by Representative Carl Hinshaw (R., Calif.) to schedule the hearings. Other members of the subcommittee are Durham, Rep. Melvin Price (D., Ill.), and Sen. William Knowland (R., Calif.).



REACTOR COOLANT PUMPS for use in the prototype submarine thermal reactor are being tested at Westinghouse, where they were designed and built. The squirrel-cage rotor of the water pump, contained in a shrink-fit jacket of steel, turns within a stator that is also fully enclosed in steel. Because the water is hot, thermally and radioactively, leakage must be at a minimum. The motors cannot drive the pumps through seals; bearings are inside the stator and are lubricated by water

Joint Committee Names Rep. Cole as Chairman

Representative W. Sterling Cole (R., N. Y.) has been unanimously chosen chairman of the Joint Congressional Committee on Atomic Energy. Senator Bourke B. Hickenlooper (R., Iowa), the other contender for the chairmanship, has been named vice chairman.

This action came after the committee had been deadlocked for months over the naming of a chairman (NU, March '53, p. 70). The Senate members contended that the chairman should be a Senator. The House members contended that the chairmanship should rotate and pointed out that the chair had, up to this time, been held by a Senator.

At the meeting at which Cole was chosen, the committee unanimously accepted a resolution that the chairmanship be rotated every two years between House and Senate. This means that Cole will remain chairman through 1954, when the 83rd Congress adjourns.

The subcommittee hearings on private nuclear power development, under the direction of Rep. Carl Hinshaw (R. Calif.), will not be affected by the selection of Cole.

Homogeneous Reactor Generates 150 kw

The production of useful amounts of electric power by nuclear energy has been achieved from the successful operation of the experimental homogeneous reactor at Oak Ridge National Laboratory. The reactor was brought up to its full design power of 1,000 kw of heat output which was used to run a turbine generator, and about 150 kw of electricity was produced. This is enough power to meet the needs of 50 average 5-room dwellings.

Capable of producing both fissionable material and power, the reactor has been under construction since

March, 1951. The construction was preceded by two years of development and design work at Oak Ridge. The reactor went critical on April 15, 1952, less than a year before it was brought to full power.

John A. Swartout, deputy research director of ORNL and director of the homogeneous reactor project, emphasized that many problems remain to be solved concerning this reactor in which a single homogeneous solution served as fuel, moderator, and coolant. Although the experimental reactor was not designed to produce economic electric power, the success of its operation is an important milestone toward that end.

Construction and fabrication of the reactor and its auxiliaries, including building and site facilities, cost about $1.1-million; cost of research and development was about $3-million.

Engineering design and construction were supervised by C. E. Winters. Actual construction and experimental testing of the reactor were supervised by S. E. Beall.

Lewis L. Strauss, Former AEC Member, Takes Job as Presidential Adviser on Atomic Energy

Lewis L. Strauss, member of the Atomic Energy Commission from 1946 to 1950, has been appointed a special advisor to President Eisenhower on atomic energy matters. Since no one else on the White House staff even pretends to any competence in the field, Strauss will be largely responsible for any executive action in atomic energy.

When he was with AEC, Strauss earned a reputation as an exponent of private enterprise in nuclear energy. He also deplored heavy spending by the government at any point where industry might be tempted to do the job. This might indicate that he will oppose large investment of government funds in atomic power development, even on an experimental basis, provided industry is inclined to spend its own money for this purpose.

Two urgent problems that have almost certainly been dumped in Strauss' lap are:

1. How far along are the Russians in atomic weapons development, and what are we to do about it?

2. What needs to be done to get industry into peacetime atomic work, particularly the production of electric power?

On the answers to the first question hangs the future of the government's atomic weapons program. AEC already has sent the White House a top secret report on Russian bomb progress. If the report looks grim to Strauss, there will probably be a speed-up in production of atomic and hydrogen bombs and related weapons.

As to the second question, Congressional hearings on the development of nuclear power have been resumed. What AEC representatives say at these hearings will have a lot to do with what the Congress does. But the President, to whom AEC is directly responsible administratively, must take a stand on the problem. This is where Strauss' experience and views will come into the picture.

A slightly less pressing problem for Strauss is the selection of a new chairman for AEC to succeed Gordon Dean, who will leave AEC in June (NU, March '53, p. 70).

There's little doubt that Strauss himself could have the chairmanship if he wanted it. Some White House observers insist he was offered the job but turned it down to become an Eisenhower adviser. That still doesn't rule out his acceptance of the job eventually if he fails to come up with the kind of a man he wants for the job by June.

Canadian AEC Ships 7 Different Isotopes

The isotopes branch of the Canadian National Research Council made a total of 655 shipments of 7 different radioisotopes during the period from April 1, 1951, to March 31, 1952.

The quantities of isotopes shipped during that period are, according to the 1952 edition of the National Research Council Review, 2,652 curies of Co^{60}, 32,855 mc of Na^{24}, 20,020 mc of I^{131}, 2,377 mc of P^{32}, 1,114 mc of C^{14}, 715 mc of S^{35}, and 175 mc of Ca^{45}.

Of the shipments made, 226 were to the NRC Atomic Energy Project, 200 to Eldorado Mining and Refining (1944) Ltd., 68 to Charles E. Frosst and Co., and 42 to other Canadian users. The Atomic Energy Research Establishment, Harwell, received 83 shipments, and the U. S. Atomic Energy Commission received 36.

These isotopes were produced in the NRX reactor at Chalk River, now under repair following an accident (NU, March '53, p. 70). During the repair period, Canadian users will be supplied with isotopes from stock and from the U. S. Isotopes identical to those from NRX are being secured for most research and medical purposes. Some more penetrating isotopes, such as Na^{24}, are now more difficult to obtain in required strength because of the lower flux of U. S. reactors and the longer time required for shipment of the isotopes from the U. S.

George Prout Dies; Was GE Atomic Energy Head

George R. Prout, vice president in charge of General Electric Co.'s nucleonic and atomic projects, died last month at the age of 53 after a two-week illness. Mr. Prout was responsible for all the company's atomic energy activities, including the Hanford plutonium plant and the Knolls Atomic Power Laboratory. He was also responsible for coordinating activities with the Atomic Energy Commission among all organizations in the company.

Fuel Recovery Plant Uses New Design Ideas

A new plant for recovery of fissionable material from used reactor fuel elements has been put in operation at the National Reactor Testing Station, Arco, Idaho. The plant is said to embody some new design concepts, including direct maintenance, and the new design ideas are expected to supply data of importance in the economics of reactor utilization.

Previously, such processing plants have had provision for remote control replacement of defective units. The new plant is expected to demonstrate the feasibility of direct maintenance by decontaminating the individual cells in which the chemical processing is carried out.

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in the process has also been installed. Such gas-purification apparatus would be of great value if, in the future, recovery plants are put up near reactors at centers of population.

Construction of the facility required 38 miles of stainless-steel tube and pipe, 125 miles of aluminum and copper tube and carbon-steel pipe, and 35,000 square feet of sheet stainless steel. The plant is operated for the Atomic Energy Commission by the American Cyanamid Co., N. Y.

New Hospital for Cancer Research and Treatment

An eight-story hospital, devoted solely to treatment of cancer and investigations on radiotherapy, has been formally opened in Chicago. Called the Argonne Cancer Research Hospital, it will have facilities for the use of all known types of radiation and radiation sources thought to be useful in cancer treatment.

Equipment includes a 2-Mev Van de Graaff generator, a 50-Mev linear accelerator, a rotating cobalt "bomb," two 250-kv X-ray machines, smaller X-ray machines, and facilities for use of radioisotopes. In addition to these, arrangements are being made for use of the 450-Mev proton synchrocyclotron at the University of Chicago's Institute for Nuclear Studies.

Most of the building houses the laboratories and radiation sources. Only two floors are for patient care; they provide 56 beds. To prevent possible spread of contamination, the individual patient rooms are separated by 8-in. concrete walls, and floors are plastic covered.

Twelve 12,000-gallon storage tanks are located in the sub-basement (see cover picture). In these tanks, radioactive wastes are accumulated until they are inactive or are disposed of through Atomic Energy Commission facilities.

Processing and storage space for radioactive materials are located in the basement (see illustration below).

Heavily shielded rooms for irradiation of both patients and animals are also located in the sub-basement. The viewing windows for these rooms are 3 ft thick and are filled with zinc bromide solution.

The Co^{60} source, expected to be in operation by summer, will be shielded by uranium rather than lead. This will permit a weight reduction from the usual 4,000 down to 950 pounds.

The hospital, built with $4.2-million of AEC funds, will be operated by the University of Chicago, under the direction of Leon O. Jacobson. Facilities of the hospital will be available to the Argonne National Laboratory and the 32 universities and research institutions of the mid-west which are participating members of Argonne.

To Discuss Management's Isotope Problems

The Oak Ridge Institute of Nuclear Studies will sponsor a two-day symposium on management problems in the use of radioisotopes in industry on April 30 and May 1. The symposium will follow the completion of a two-

STORAGE OF RADIOISOTOPES at Argonne Cancer Hospital is in 40 8-ft-long stainless-steel tubes embedded in concrete and shielded with lead caps. The isotopes themselves are placed in 2-ft-long lead containers which fit inside the stainless-steel tubes

week advanced course in isotope techniques in industry. It is expected that the scientific group will remain for the management symposium, and it is hoped that a community of interest will be established that will be of value to both groups.

The titles of the talks and the speakers for the first day are: *Summary of Technical Sessions*, Edwin A. Wiggin, Chief, Technical Reports Branch, Isotopes Division, Oak Ridge; *The Problem of Technical Information in the AEC*, Alberto F. Thompson, Chief, Technical Information Service, AEC; *Legal Aspects of the Use of Radioisotopes in Industry*, Samuel D. Estep, University of Michigan Law School; *Radiological Safety and Insurance Problems*, Reuel C. Stratton, Travelers Insurance Co.; and *Radioactivity and Public Relations*, Jerome D. Luntz, Editor, NUCLEONICS.

On the evening of the first day there will be a session entitled *The Outlook of Nuclear Science for Industry*.

The talks and speakers for the second day are: *The Place of a Consulting Laboratory in the Use of Radioisotopes in Industry*, William E. Barbour, Jr., President, Tracerlab Inc.; and *The AEC Isotopes Division and Its Relation to Industry*, George Manov, Allan Lough, Advisory Field Service, AEC, Oak Ridge.

Brookhaven Offers Gamma Irradiation Service

Facilities at Brookhaven National Laboratory, Upton, N. Y., for gamma irradiation are now available to non-Laboratory projects. These facilities were described in NUCLEONICS, March 1953, p. 18.

Industrial and university laboratories, and other AEC contractors, are now offered the gamma irradiation service and the opportunity to engage in cooperating research programs. Cobalt sources and irradiation devices are also available for sale.

Westinghouse to Make and Sell Reactor Components

Plans for a new, multimillion dollar plant to produce equipment for atomic power plants have been announced by Westinghouse Electric Corp. The facility, to be built in Harmar Township, near Pittsburgh, Pa., will engineer, manufacture, and sell products that have been developed for atomic power plants.

For the immediate future, the

Kit of piezo-electric materials includes: 2 crystal bender Bimorphs®; 2 crystal twister Bimorphs (oblong shape); 2 crystal twister Bimorphs (square shape); 1 Ceramic "B" disc; 1 Ceramic "B" tube; 1 Ceramic "B" hexagon; 2 microphone cartridges of the hearing-aid type; Instruction sheet.

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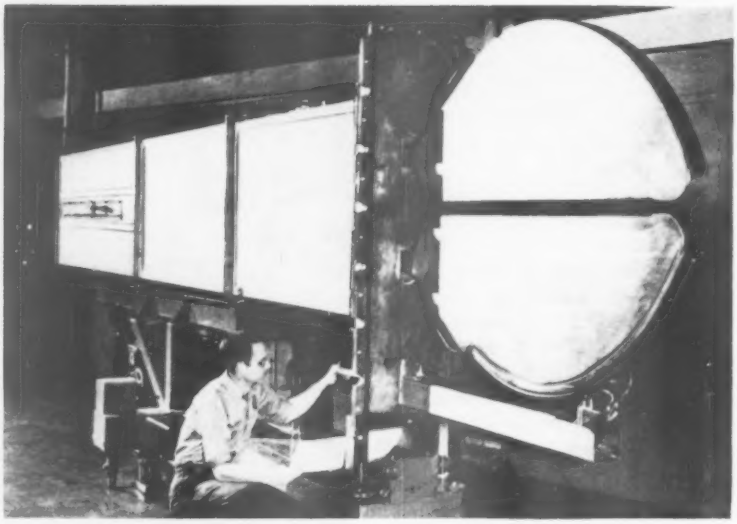

HEAVY-PARTICLE CYCLOTRON at Oak Ridge accelerates nitrogen ions to 25 Mev, which is sufficient energy for them to fuse with nuclei of other light elements. Dees are mounted in vertical position, one above the other. Target is placed at orbit radius of 25 in. and is struck by ion current of 1 μa. Accelerator operates on fixed frequency of 5.1 Mc; pole pieces have diameter of 63 in., gap of 6 in., and field strength of 15,000 gauss. Power input to oscillator is 30 kw, and r-f system operates at 60 kv, dee-to-dee

products of the new atomic equipment department of the atomic power division will go to government projects. Officials of the company believe, however, that private industry will eventually become a large customer.

The atomic power division was formed in 1948, and since that time has been engaged in development and construction of a nuclear reactor for propulsion of the submarine Nautilus. The company now also holds a contract for a similar plant to propel a large vessel, such as an aircraft carrier.

The new department will be managed by William C. Miller. The manager of the division is Charles H. Weaver.

Nuclear Science Committee Gets New Members

The National Academy of Sciences-National Research Council has announced a reconstitution of the membership of its subcommittee on shipment of radioactive substances and the formation of a new subcommittee on nuclear geophysics of the committee on nuclear science.

♦ R. D. Evans, Massachusetts Institute of Technology, is chairman of the subcommittee on shipment of radioactive substances. The other members are L. F. Curtiss, National Bureau of Standards; W. G. McKenna, Bureau of Explosives; W. S. Michel, National Research Council of Canada; K. Z. Morgan, Oak Ridge National Laboratory; H. E. Seemann, Eastman Kodak Co.; and Forrest Western, Atomic Energy Commission.

L. T. Aldrich, Carnegie Institution of Washington, is chairman of the new subcommittee on nuclear geophysics. The other members are P. M. Hurley, MIT; M. G. Inghram, University of Chicago; and A. O. Nier, University of Minnesota.

RAW MATERIALS

• **Colorado.** Mines in this state produced $50-million worth of uranium last year.

• **New York.** Carborundum Metals Co., Akron, will start production of zirconium and hafnium in July with a $25-million plant designed by Rust Process Design Co., Pittsburgh.

• **India.** A new mineral, containing 31% thorium oxide and 4% uranium oxide, has been found in Travancore and named cheralite, after Chera, the ancient name of the state.

• **Madagascar.** A plant to refine uranium ore has started operations in this French ruled island. The plant, first in any French overseas territory, will treat native ores for shipment to France.

• **Sweden.** A plant is being built at Kvarntorp for the extraction of uranium from shale. The uranium con-

centration in the shale, of which Sweden has large deposits, is about 200 gm per metric ton. But the shale also contains kolm, a hydrocarbon that contains up to 3,000 gm of uranium per ton. A process has been developed in Sweden for extracting this kolm from the shale.

IN BRIEF

• **Kilocurie industrial source.** A 4,500-curie Co^{60} source has been installed at the radiation engineering laboratory of the Stanford Research Institute. The institute will now provide a center for investigation of industrial applications of nuclear energy.

• **Nuclear engineers.** According to D. W. McLenegan, technical personnel manager at Hanford Works, the atomic energy industry doesn't want nuclear engineers. He recommends that students prepare for nuclear engineering by getting solid ground work in the separate technologies of engineering.

• **Radiocarbon dating.** Laboratories for age determination by Libby's radiocarbon method are being established at both the University of Arizona and the University of Texas.

• **Cyclotron in Japan.** The largest cyclotron in Japan, under construction at Kyoto University, is expected to be finished by the end of the year. The 15-Mev machine will replace the similar one that was destroyed by occupation forces while it was under construction.

NUCLEAR NEWSMAKERS

Frederick M. Belmore has been appointed deputy manager of AEC's New York Operations Office. A chemical engineer, Belmore has been director of production for NYOO since 1947.

Mark Mills is now serving on the panel for fuels and propulsion of the scientific advisory board of the Air Force. He is also on AEC's reactor safeguard committee, and was formerly group leader in North American Aviation's atomic energy research department.

Sylvan Wallach, formerly associated with the atomic power division of Westinghouse, has been appointed senior scientist on reactor design development at Walter Kidde Nuclear Laboratories.

William Mitchell has been appointed general counsel to AEC.

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Model E-6/2-5

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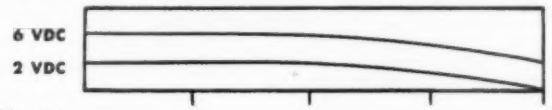

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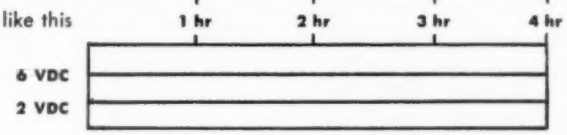

Haven't you been plagued by input voltage drop, particularly in the course of long-running experiments? Or have you had to interrupt or defer work while batteries were being charged or replaced?

The Sorensen Model E-6/2-5 Nobatron* has been specifically designed to exclude this difficulty. Using it, you can be sure your equipment is getting 2 and 6 volts DC, **plus or minus 0.01%,** with that accuracy maintained indefinitely at normal room temperature.

Furthermore, circuitry developed for the Model E-6/2-5 Nobatron is advanced in simplicity, involving no moving parts. That means easy maintenance, trouble-free operation. *Write for information.*

SPECIFICATIONS

Input voltage range	95-130VAC, 1Φ, 50-60 cycles
Output	
#1 for lamp	6VDC adjustable ±10% at 5 amperes
#2 for filament	6VDC at 100 Ma.
#3 for bias	2VDC adjustable ±10% at 100 Ma.
Filtering	
#1	1% max.
#2 & 3	0.05% max.
Regulation accuracy	±0.01% against line changes
Time constant	0.1 seconds under most severe line changes
Size:	17 x 12¼ x 17 self contained 19 x 12¼ panel for relay rack mounting
Weight:	Approximately 90 pounds
Meters:	No meters are provided due to the extreme regulation accuracy involved.

*Reg. U. S. Pat. Off. by Sorensen & Co., Inc.

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LETTERS

Modifying the McMahon Act

DEAR SIR:

In discussion of possible changes in the Atomic Energy Act of 1946, many ramifications of the effect of these changes have been introduced. But let us speak here of goals. What is the structure which the atomic energy law should try to create? I believe that the law should strive for a two-part result; the first part, a strong and substantive, civilian Atomic Energy Commission, and the second, a large and vigorous civilian atomic power industry.

In broad strokes the AEC should continue to have the major and satisfying responsibilities of:

1. An Arsenal providing for a *minimum* production of fissionable materials for weapons, and all of the manufacture of weapons themselves.

2. An "NACA" (National Advisory Committee for Aeronautics) of national laboratories responsible for a sufficient measure of technical advancement.

3. A supervisory and regulatory body at least responsible for safety, health, security and accountability problems.

Clearly these are not all of the responsibilities that the AEC now accepts; for instance raw materials operations raise important problems.

The civilian atomic power industry should have a production capacity for fissionable materials which is *many times*, let us say more than ten times, greater than that of the government arsenal. This large civilian production capacity would transform the present AEC production goal from an *upper* limit (Gordon Dean; American Bar Association, San Francisco, Cal., Sept. 17, 1952) to the *minimum* which it really is if the country's defense objectives depend upon it. The larger civilian production capacity would eliminate the nagging worry, whether or not anyone can really predict a war's demands for fissionable material for atomic weapons and atom-powered ships and planes. It would provide a material strength entirely consistent with and analagous to the many reserve strengths which free enterprises provide for our land, "stand-by" defense strengths which cost the Treasury nothing in peacetime, and which are so priceless in wartime. It would also provide that other strength, the insurance against total error, which comes from multiple centers of decision.

Now let us switch from goals to means. How can the law do its part toward achieving these goals? On two points there is little controversy.

First, the law must be modified to permit private companies to own facilities for the production of power and fissionable materials.

Second, the law needs to empower the Commission to enter into long-term arrangements providing for a supply of both source and fissionable materials to industry. These minimum requirements are rather broadly recognized.

However, there are various views on the question of the ownership and sale and disposition of fissionable materials manufactured by industry. Some maintain the viewpoint that the government should retain ownership of new fissionable materials manufactured by industry, and pay a government-determined price therefore. In my opinion, the above arrangement would tend strongly to prevent the growth of a vigorous and healthy industry.

I believe that the companies should have the right to own the fissionable materials. They should also have the right *not* to sell their product, and the right to sell it to other private parties *who are licensed* by the Commission to receive fissionable materials. The law should be modified to permit private companies to own fissionable materials *per se*, in addition to the facilities for their production.

In this manner a partly free market can exist in which both the government *and other users* of energy will create a demand for fissionable material which can be marketed at a profit. Clearly, the government should have an overriding call on all new production in times of military emergency. But, for the long-term, the really active market would be between private producers of fissionable material and private purchasers thereof. Thus, I would anticipate that Dow–Detroit Edison might be allowed to make a profitable sale, not government audited, to let us say, the Philadelphia Electric Company, who would have been previously licensed to purchase fissionable material, and who would be intent upon building their own nuclear power plant.

Clearly, the government might wish to maintain a bid for fissionable material in this market for its stockpile. This government bid might be a very important factor at the beginnings of the free civilian enterprise. But, over a long term, this factor should be of distinctly lesser importance than the needs of utilities to provide for their normal expansion of power production.

It may be that companies borrowing fissionable material to get started with breeding plants ought to recognize as a first charge on their production the return of the borrowed amounts to the government stockpile before private sales would be reasonable.

It would seem that the only reasonable constitutional bases for AEC supervision and regulation will lie in the two broad grants of power to Congress, to provide for defense, and to regulate interstate commerce. It should be noted that these powers are limited and do leave some areas for eventual state regulation.

JOHN R. MENKE, *President*
Nuclear Development Associates, Inc.
White Plains, New York

World Progress

DEAR SIR:

I read with much interest the paper devoted to recent nuclear developments in West European countries. ("World Progress in Atomic Energy," NU, Dec. '52, p. 7.) I should like to add some complement of information to that you published.

Nothing is said in your article about research at the Royal Military Academy, Brussels, whose nuclear center is directed by Prof. R. Ledrus. A 1.4-Mev Cockroft Walton generator has been installed there by Ateliers de Constructions Electriques de Charleroi. A linear proton accelerator, probably of the helix type, will also be built there. Extensive work on ion guns has been done by Lt. Col. Thomas.

Furthermore, you mention the Philips organization twice as the manufacturer of nuclear tools in Belgium. But a very important segment of these tools have been manufactured by Ateliers de Constructions Electriques de Charleroi—i.e., the main parts of the cyclotron at Louvain, parts of the mass spectrograph at Louvain, detecting devices and counting equipment.

I should like to mention too that Paul Capron (and not Caprin) and Jean Delfosse are not assistants of Prof. Count Marc de Hemptinne, but professors themselves.

MAX HOYAUX
Electronics Division
Ateliers de Constructions Electriques de Charleroi
Charleroi, Belgium

New AEC Patent Releases

The following patents, released by the Atomic Energy Commission, are available for royalty-free, nonexclusive licensing. Applicants should apply to the Chief, Patent Branch, Office of the Counsel, U. S. Atomic Energy Commission, Washington 25, D. C. Identify patents by number and title.

Analyzer (2,620,256) Q. A. Kerns, L. W. Whitcomb, E. E. Brown—analyzer and recorder continuously and simultaneously record relation between two variables by means of movable table and stylus, each controlled by a phase-sensitive motor.

Radiation Detection and Measuring Means (2,620,446) H. D. Le Vine, H. J. Di Giovanni—without amplification, circuit measures d-c component of G-M tube discharge current up to several hundred r/hr.

Ion Source (2,621,296) R. W. Thompson—apparatus particularly suited to generating ions of heavy metals from vaporizable compounds of metal in vacuo. Ion ratios are quite constant and controllable.

Receptacle (2,621,912) R. N. Lyon, S. G. Bankoff, F. J. Smetana—baffle means of quenching container effect random distribution of elongated members dumped into it.

Production of Carbon Dioxide (2,622,008) W. W. Miller, J. Turkevich, N. Zwiebel—radioactive carbon dioxide liberated from an alkaline earth carbonate by heating a mixture of the carbonate and a dry metal halide to 400–500° C at $<10^{-2}$ mm Hg.

Method for Preparing Boron Trifluoride (2,622,014) I. Kirshenbaum—BF_3 prepared by heating a dry mixture of a boron oxide and a higher metal fluoride at 115–190° C and 1 atm and collecting BF_3 gas.

Automatic Cable Tester or Fault Analyzer Means (2,622,130) L. J. Kabell, R. A. Richards, A. L. Dyer—apparatus automatically tests a cable having a plurality of wires for faults of

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Voltage: 0.75-2.0 MV

Ion beam: 50 μa total
25 μa analyzed

Electron beam: 100 μa for external use
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Ion-beam energy stability: ± 2 keV

Electron-beam energy stability: ± 40 keV

Neutron output from Be^9 (d, n) B^{10} reaction:.....10^{10} n/sec.

X-ray output from gold target:.....5000 r/min. at 10 cm

Electron ionizing power:.....2 x 10^7 gram-rep/sec.

Overall dimensions:....height . . . 6 feet, width . . . 4 feet
generator tank length . . . 6½ feet
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Weights, accelerator and mount: 6000 pounds.

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Mass Spectrograph (2,622,204) A. E. Shaw, W. Rall—improved double-focusing mass spectrograph has subassembly for collimating and electrostatically deflecting ion beam. Photographic-plate positioner allows numerous exposures without removal from vacuum system.

Radioactive Particle Counting (2,622,208) W. Bernstein, R. Ballentine—easily dismantled counter comprises two insulated electrodes mounted on a brass plate surrounded by a removable envelope which can be evacuated and continuously supplied with counting gas.

Ion Source (2,624,009) R. R. Wilson—multiple ion source capable of continuously producing a copious supply of gaseous ions.

Remote Control Pipetting Unit (2,624,656) H. C. Andrews, J. F. Gifford—pipette assembly has remotely controlled horizontal and vertical movement, fluid flow, interior flushing, and external washing.

Apparatus and Method for Measuring Magnetic Flux (2,624,783) V. A. Nedzel—strength of unknown field is determined by combining in opposition and measuring the difference between two emf's—one proportional to a known field and the other proportional to the unknown field.

Method of and Apparatus for Accelerating to High Energy Electrically Charged Particles (2,624,841) E. M. McMillan—describes the synchroton. Charged particles are accelerated by increasing the ratio of magnetic field strength to frequency of electric field oscillation, while maintaining the field constant.

Ion Source (2,624,845) R. W. Thompson—source for an ionic mass separating apparatus. Unit utilizes a sealed receptacle containing a relatively pure anhydrous charge material that is to be vaporized and ionized.

Ballistic Electrometer (2,624,847) W. P. Jesse, J. W. Broxon, W. H. Hinch—measures and records extremely small electric currents, such as ion currents produced in ion chambers subjected to low intensity radiation.

Arc Hash Analyzer by Cathode-Ray Tube (2,624,860) W. R. Baker—useful in visually presenting on the cathode-tube screen the wave form existing during a selected time interval of any section of an electrical signal.

Method of Electrodepositing Nickel (2,625,507) S. A. Mayper—produces

Want more information? Use post card on last page.

nickel powder having particle size of 7–15 microns. With inert cathode, nickel and carbon anodes, and solution of 0.1M nickel, 1M sodium and 1M ammonium, adjust current carried by anodes to maintain constant nickel ion concentration.

Coincidence Circuit (2,625,653) L. F. Wouters—with photomultiplier-tube coincidence circuit, useful for determining phase relationship between accelerating radiofrequency voltage and particles of a particle accelerator.

Monitoring Gas for Radioactive Xenon (2,625,657) W. R. Kanne—ionization chamber is arranged so that ions carried along by the incoming gas are grounded out prior to the gas entering the ionization chamber.

Method of Making Zirconium Tetrachloride (2,626,203) W. B. Blumenthal—ZrF_4 is reacted with $MgCl_2$ at 350–900° C; $ZrCl_4$ distilled from reaction mass.

Method of Polymerizing Trifluorochloroethylene (2,626,254) W. T. Miller, J. T. Maynard—polytrifluoromonochloroethylene prepared by contacting a completely halogenated acetyl halide or acetic anhydride to produce the peroxide of the acetyl compound in situ; and maintaining at a temperature to decompose the peroxide and to cause polymerization.

Beam Extractor (2,626,351) W. M. Powell—apparatus removes charged-particle beam from accelerator by applying a high-voltage pulse to deflecting electrodes when ions of a desired energy level are within the influence of the electrodes.

Target for Particle Accelerators (2,626,359) F. R. Weber, Jr.—target assembly mounts a number of samples, oscillates any one of the samples in the beam for uniform irradiation, and changes sample targets by remote control.

Comparative Photometer (2,626,-989) A. A. Brown—method and apparatus for production of comparative photographs of relative motion between a comparative photometry assembly and the objects to be scanned.

Amplifier Circuit for Testing (2,628,-268) Q. A. Kerns—circuit for determining current-voltage characteristics provides a minimum of distortion of amplifier output.

Shielded Switch Assembly (2,628,-297) C. T. Grauer—magnetically operated flow switch, adapted for use in a strong disturbing magnetic field, employs a ferromagnetic shield in the region of magnetic control elements.

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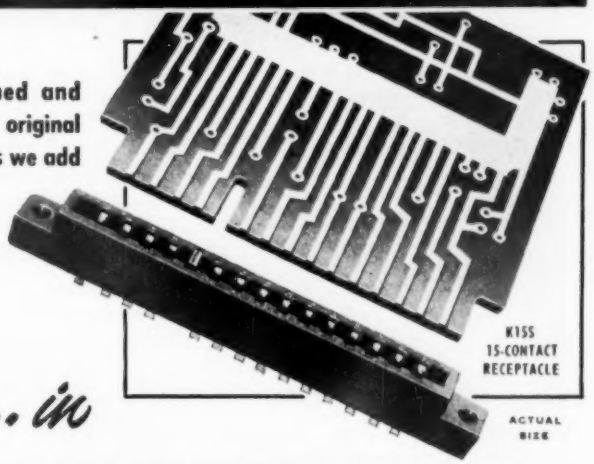

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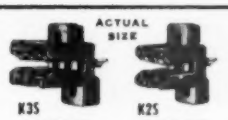

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MONOBLOC* CONSTRUCTION eliminates unnecessary creepage paths and reduces the number of moisture and dust pockets.

MOLDED MELAMINE bodies (in accordance with MIL-P-14) mineral filled ... are fungus-proof and provide mechanical strength as well as high arc and dielectric resistance.

CONTACTS are spring temper phosphor bronze (QQ-B746a), gold plated over silver for low contact resistance, prevention of corrosion and ease of soldering.

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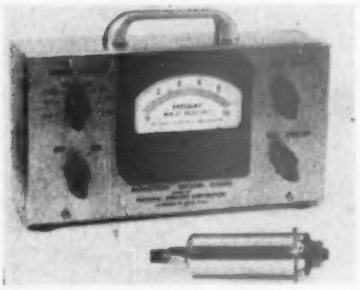
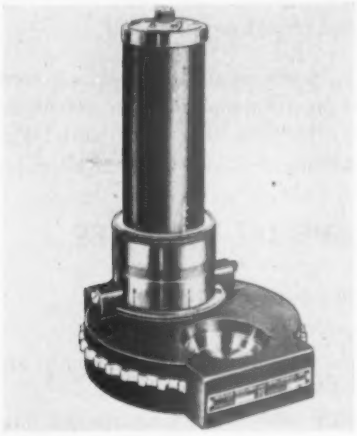


Vacuum Gage

National Research Corp., 70 Memorial Drive, Cambridge, Mass. The type 511 battery-powered vacuum gage has ranges of zero to 1,000, 100, 10, 1, 0.1 and 0.01 mm with accuracy of ±2% of full scale; in the last range it measures to 0.0001 mm. Similar to hot-filament vacuum gage operation, ionization current produced by alpha particles is measured by a d-c amplifier. Since pressure response is instantaneous, the gage may be used as a leak detector. (P-1)

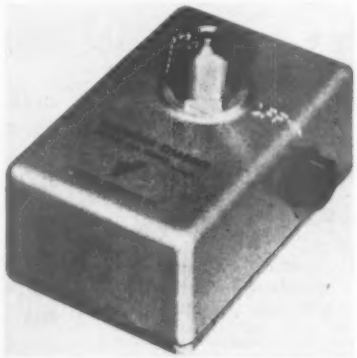


Scintillation Counter

Nuclear Research and Development, Inc., 1094 Sutter Ave., St. Louis 5, Mo. The Radimax scintillation counter is adaptable to various counting problems by using the following counting heads with a single phototube housing: windowless alpha, beta, gamma rotating planchet (see illustration); three-position turret head for any combination of gamma, beta, alpha or neutron phosphors; collimated medical head; standard gamma head with variable-size crystals; and standard beta head, with anthracene or plastic phosphor. The basic unit consists of a RCA 5819 tube, mumetal magnetic shield, and dropping resistors. (P-2)

Scintillation Plastic

National Radiac, Inc., 10 Crawford St., Newark 2, N. J. Sintilon scintillation plastic, sensitive to gamma, beta, alpha, X-rays and ultraviolet light, has a decay time of 1.0×10^{-8} sec. Tested with radium gamma rays, it is claimed to show a counting rate of 90% when compared with an anthracene crystal of the same weight. The plastic can be molded or machined and is transparent and durable. (P-3)

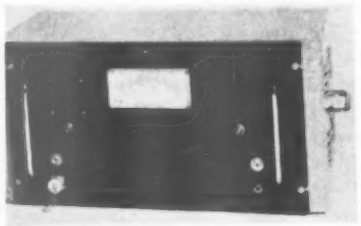


Dosimeter Charger

Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio. The model 561 dosimeter charger charges all makes of direct-reading pocket dosimeters in the range 110–225 volts. Off-on-charge knob and spring-loaded charger socket prevent damage to the dosimeter due to excessive pressure by the operator. The 3-lb unit is waterproof. Power supply is ten 22½-volt and one 1½-volt batteries. (P-4)

Film Hanger

Bar-Ray Products, Inc., 209-25th St., Brooklyn 32, N. Y. This film hanger allows instant loading and unloading of X-ray films without the use of clips, thus avoiding clip holes, films sticking together or scratched film surfaces. Made of stainless steel, it is available in 10 and 14-film holders. (P-5)



Counting-Rate Meter

Isotope Developments, Ltd., Finsbury Pavement House, 120 Moorgate, London, E. C. 2, England. The type 550 counting-rate meter has ranges of zero to 10, 100 and 1,000 cps for G-M counters and 10,000 cps for scintillation or proportional counters. The type 510 prescaler extends the range to 100,000 cps. Deadtimes of the ranges 10 to 10,000 are 2,000, 200, 200 and 20 μsec, respectively. Input requirements are positive pulses of height greater than 5 volts. Accuracy is better than ±1%, full scale; drift is $<\pm 1.0\%$ in 8 hr; and regulation is better than 1.0% with 10% change in line voltage. A high-voltage supply, continuously variable between 300 and 600 volts, is provided for halogen-quenched G-M counters. (P-6)

Source Container

Tracerlab, Inc., 130 High St., Boston 10, Mass. The E-31B high-intensity source container holds up to 800 mc of activity. Radiation from an 800-mc Co^{60} source is <10 mr/hr at 1 m. An outer shell of ⅜-in. malleable iron filled with lead provides shielding equivalent to 4 in. of lead. The cover pivots up and back, erecting a 4-in.

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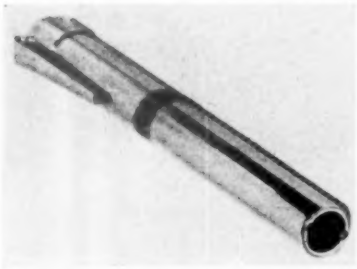
lead shield between the exposed source and the user. A removable lead insert, 1 in. in diameter and 1 in. long, holds the source. The container weighs 150 lb and is $10\frac{3}{4}$ in. high. (P-7)

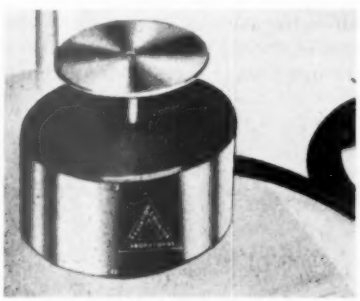


Neutron, γ-Ray Dosimeter

Landsverk Electrometer Co., 550 W. Garfield Ave., Glendale 4, Calif. This combined neutron and gamma-ray dosimeter is made as a direct-reading quartz-fiber dosimeter, model L-29, and a pocket chamber, model L-69. The full-scale reading for X and γ-rays is 200 mr; for slow and thermal neutrons, full-scale reading is 200 mrep. (P-8)

Organic Scintillators

Pilot Chemicals, Inc., 47 Felton St., Waltham 54, Mass. These fluorescent chemicals can be used in solution, incorporated in plastics, or grown into large single crystals. Among the fluors offered are diphenylhexatriene, tetraphenylbutadiene, quaterphenyl. (P-9)

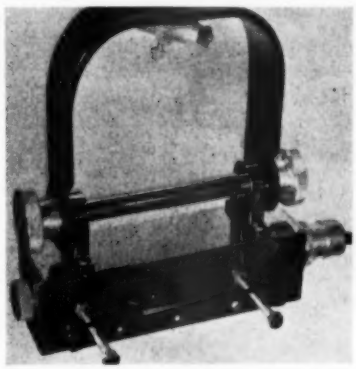


Sample Spinner

Radiation Counter Laboratories, Inc., Dept. FP-2, 5122 W. Grove St., Nucleonic Park, Skokie, Ill. This sample spinner is designed for the preparation of samples from slurrys or low-particulate dispersions in solution. Turntable speed is 20 rpm. The 4-in.-diameter spinner is made of copper with heavy chrome plating. (P-10)

Bismuth-Cathode Tube

Nucleonic Company of America, 497 Union St., Brooklyn 31, N. Y. The model BGM2 bismuth-cathode G-M counter tube is an all-metal, sausage-type gamma tube with helium and organic-quenched filling. Its sensitive anode length is 5 in. Threshold is 1,000 volts; operating voltage is 1,050–1,200 volts; slope is 3% per 100 volts. Tube is claimed to have no photosensitivity and life of 10^9 counts. (P-11)

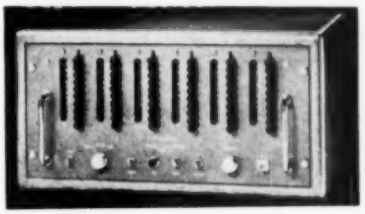


Thyroid Uptake Shield

The Atomic Center, Inc., 489 Fifth Ave., New York 17, N. Y. The thyroid uptake shield, together with the Atomlab gamma-sensitive bismuth-coated G-M tube, is used for thyroid uptake accumulation measurements and general scanning purposes. The shield consists of a $\frac{3}{4}$-in. lead housing for the tube, encased in chrome-plated brass, with over-all dimensions of $2\frac{1}{2} \times 2\frac{1}{2} \times 9$ in. A 5×1 in. rectangular opening on the bottom is covered by a sliding lead shutter when not in use for body surveying. The shield can be supplied with an attachment bar and yoke for swivel mounting onto any standard X-ray stand or with a wooden platform which can be bed-supported. (P-12)

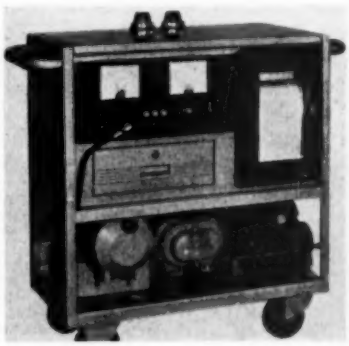
Tracer-Dose Containers

Plax Corp., 76 Talcott Rd., West Hartford, Conn. Squeezable polyethylene-plastic tubes provide convenient, nonbreakable containers for radioactive tracers for diagnostic purposes. At present, they are used for shipping radioiodine. Contamination is avoided since the tube's suction prevents dripping and permits rinsing. (P-13)



Preset Counter

Berkeley Scientific Co., 2200 Wright Ave., Richmond, Calif. This preset counter, using two to six model-730 decimal counting units, has rates of 0–40,000 cps. Output can be in the form of a 125-volt pulse or $\frac{1}{50}$-sec relay closure. In the counter position, the unit operates as a high-speed counter; in the recycle position, it gives output information at the preset number, resets, and continues to count; in the gate position, it counts to the preset number and stops. Input sensitivity is ± 1 volt, peak to peak, with respect to ground. (P-14)



Air Monitor

Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind. The model AM-2 air monitor detects and records radioactive materials in the air; an alarm bell and flashing lights warn of the presence of dangerous amounts. Air is continuously drawn through a lead-shielded cylinder of filter paper. A halogen-filled G-M tube centered in the cylinder detects deposited radioactive material. Pulses from the tube are indicated on a count-

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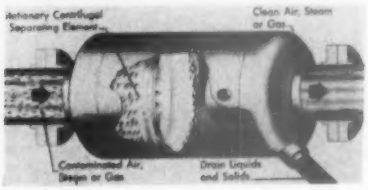
ing-rate meter and recorded by an Esterline Angus recorder. Counting-rate ranges are 0–2,000, 0–10,000 and 0–20,000 cpm; range changing is automatic. (P-15)

G-M Scaler

Able Scientific Glass Apparatus Co., 5041 W. Lake St., Chicago 44, Ill. The model 147 scale-of-64 scaler has an input sensitivity of ¼ volt. Resolving time is less than 5 μsec to pulse pairs. High voltage is continuously variable from 500 to 1,500 volts; meter calibration is 2% of full scale. The count is presented on a four-digit mechanical register. (P-16)

Pulse Generator

Radiation Instrument Co., Box 733, Silver Spring, Maryland. The model 401 pulse generator provides pulse amplitudes in 10 steps from 1 mv to 1 volt, positive or negative, from an internal supply. With an external supply, the generator gives pulses up to 45 volts, continuously variable. The repetition rate is 3,600 ppm. Rise time is <0.003 μsec; *R-C* decay-times of 1, 10 and 100 μsec are selectable. (P-17)


Stationary Centrifugal Separating Element
Clean Air, Steam or Gas
Contaminated Air, Steam or Gas
Drain Liquids and Solids

Gas Purifier

V. D. Anderson Co., Purifier Division, 1935 W. 96th St., Cleveland 2, Ohio. The Hi-eF line-type purifier is claimed to remove virtually 100% of dirt and moisture from steam, gas, and vapor lines through a stationary centrifugal separating element. The purifier is made in all standard sizes up to 24 in. for pressures up to 600 psig; larger sizes and special designs are made to order. All units have forged-steel flanges with borders of welded-steel construction. (P-18)

Micromanipulator

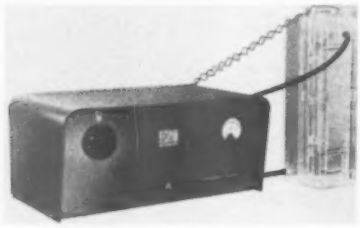
Microchemical Specialties Co., 1834 University Ave., Berkeley 3, Calif. This inexpensive rack-and-pinion-type micromanipulator has 2 in. of travel in three planes. The tool holder accommodates small hand vise or special tools, glass tubing or rods. The instrument handles Benedetti-Pischler techniques and may be used in conjunction with a stereoscopic microscope at low power. (P-19)

Standard Inductors

General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass. The type 1482 standard inductors, in 1, 2, 5-unit values, are available from 100 μh to 1 h. Accuracy is 0.1% (0.25% for 100 and 200 μh inductors). Each unit has a calibration certificate including inductance, d-c resistance, and temperature coefficient. (P-20)

Sources and Absorbers

Isotopes Specialties Co., 3816 San Fernando Rd., Glendale, Calif. Included in the calibration sources offered are alpha, beta and gamma sources and split sources for determining coincidence correction of radiation detection instruments. Absorber sets include twenty-five aluminum and five lead disks selected to give complete curves for beta-particles and soft gammas and X-rays. (P-21)



Fractionation Apparatus

Beckman Instruments, Inc., South Pasadena, Calif. The electrophoresis-convection apparatus is claimed to carry out the separation of proteins possessing closely related physical and chemical properties unfractionable by previous methods. The apparatus includes a fractionation cell, two platinum electrodes, the buffer container which houses the fractionation cell and electrodes, and the control unit which contains the 110 a-c power pack and buffer circulation pump. Several fractionations may be conducted at the same time by cascading units. (P-22)

Volumetric Flasks

E. Machlett & Son, 220 E. 23rd St., New York 10, N. Y. The Emson volumetric flasks have a Schellbach-type background superimposed on a graduation mark filled in with yellow pigment. The background, against which the solution level is seen, consists of a vertical blue stripe running through a white area. Stoppered and unstoppered flasks are available from 10 to 2,000 ml. (P-23)

Electrometer

Special Instruments Laboratory, Inc., 1003 Highland Ave., Knoxville, Tenn. The model 145 electrometer measures d-c voltages from 0 to 150 mv and

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currents of 10^{-8}–10^{-16} amperes. A range switch selects input impedance values of 10^{9}, 10^{10}, 10^{11}, or 10^{12} ohms when the test chamber is used. Input impedance of the probe is fixed at 10^{12} ohms. The instrument can be calibrated for any full-scale deflection from 30 to 250 mv. Bucking voltage is available from a 10-turn Helipot at 1 or 10 volts full scale. (P-24)

Recording System

Edin Co., Inc., Dept. E-6, 207 Main St., Worcester 8, Mass. The Consolette is a recording system with a-c, d-c or carrier amplifiers with an oscillograph recorder. The system can be expanded from 2 channels to 4 or 6 channels by the addition of recording galvanometers and amplifiers. Ink-writing galvanometers cover the range from d-c to 300 cps. Recorder chart-paper speeds are available from 0.1 mm/sec to 625 mm/sec; 3 or 9 inclusive chart speeds are optional. Space is provided for chart rolls and accordian-folded multichannel chart paper. (P-25)

Decade Counter Switch

The Daven Co., Dept. DC, 191 Central Ave., Newark 4, N. J. The model 410 decade counter switch is designed for

VICTOREEN POCKET DOSIMETERS

Engineered for Lasting Performance

You can be confident that Victoreen's long experience in radiation measurement is an integral part of the performance you buy and expect in Victoreen Pocket Dosimeters.

The Model 541/A Pocket Dosimeter consists of an hermetically-sealed ionization chamber with a built-in quartz fiber electrometer (0 to 200 Milli-roentgen) and optical system for direct reading of exposure to X-ray and gamma radiation at any time.

OUR GUARANTEE OF CHAMBER PERFORMANCE

Thorough engineering to ensure that these chambers, when made available, would be the *best*.

X-ray and Cobalt calibration—using facilities second to none—so that we *know* their performance.

Careful production and hermetic sealing—in electronically filtered, air-conditioned assembly rooms.

Thorough electrical, structural, and environmental testing—to rigid specifications.

New

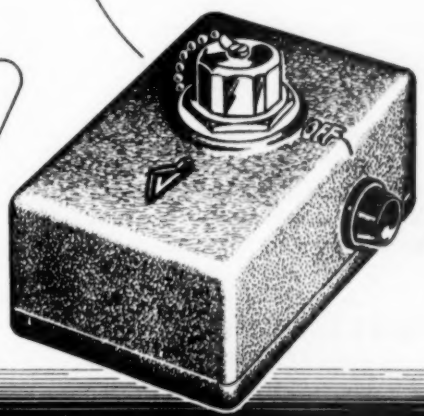
VICTOREEN 561 CHARGER

Designed to charge all standard direct-reading quartz fiber dosimeters to any voltage between 110 and 225 volts.

- Spring-loaded charging socket
- Single off-on-charge knob
- Compact, waterproof case
- Battery operated

write

Ask for bulletin 3012 containing detailed specifications for all Victoreen dosimeters and chargers.



INSTRUMENT DIVISION

The Victoreen Instrument Co.

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OPTICAL SYSTEMS

INDUSTRIAL PERISCOPES

DESIGN

DEVELOPMENT

MANUFACTURE

For nearly half a century Kollmorgen has designed, developed and manufactured precision optics and optical systems for industry and the military.

We have the engineering "know-how", the design personnel and the manufacturing capacity to help you solve *your* optical problem.

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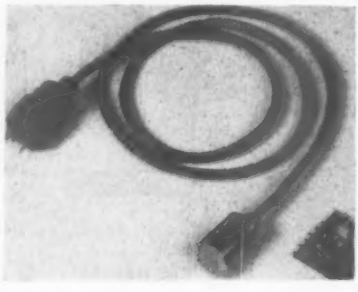
work which requires indication of shaft position at a remote point. Analogous to operation of a visual counter indicator, electrical contact is provided in place of each digit seen on the scale of the number wheels. Five contact-panel decades provide a total of 99,999 switch positions; the number of panels can be varied. The unit operates up to 500 rpm and has 1,000-volt, d-c, insulation. (P-26)



Miniature Pressure Transducer

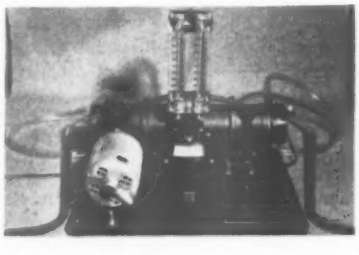
Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif. The type 4-310 pressure transducer, ½ in. in diameter and ¾ in. long, is designed for direct insertion into a process vessel or stream of liquid or gas. Available ranges are 5, 15, 50, and 150 psig with nominal open-circuit sensitivity of 1.5 mv/v at full-rated pressure. Temperature range is −65 to 165° F. The unit may be used with recorders or visual indicators. (P-27)

Microwave Signal Sources

Polarad Electronics Corp., 100 Metropolitan Ave., Brooklyn 11, N. Y. This series of microwave signal sources covers the range of 634–10,750 Mc, in five units. Frequency can be read directly to 10% accuracy. A reflex klystron is the source of energy; a single dial controls cavity frequency and reflector voltage. Modulation inputs for the signal sources are available on the front panel. (P-28)

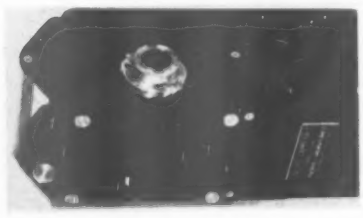
Regulated Power Supply

Kepco Laboratories, 131-38 Sanford Ave., Flushing, N. Y. The model 700 regulated power supply delivers 0–750 ma, continuously variable from 0–350 volts. In the range 30–350 volts, output voltage variation is $<\frac{1}{2}\%$ for line fluctuations from 105–125 volts and for load variation from minimum to maximum current. Ripple is <10 mv, peak to peak. (P-29)



Air Filter Tester

Trion, Inc., 1000 Island Ave., McKees Rocks, Pa. This portable instrument tests the efficiency of all types of air filters. Air samples are drawn through filter paper; photoelectric measurement of light transmission through the paper then determines the degree of air contamination. A continuous record for any time period is claimed to have an accuracy of 10–95%. (P-30)



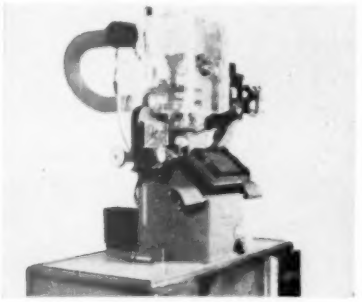
Recorder Camera

Pacific Laboratories, 12808 Venice Blvd., Venice, Calif. The type V-10 35-mm, remotely controlled camera

operates continuously at 16 frames/sec or intermittently at preselected rates. Operating conditions are −50 to 180° F, 0 to 85,000 ft, and 95% humidity. Power requirements are 5 amperes at 22–29 volts, d-c. The camera weighs 13 lb and occupies 300 in.³ (P-31)

Portable Gas Analyzer

Gow-Mac Instrument Co., 22 Lawrence St., Newark 5, N. J. The Gas Master is a portable instrument for quantitative gas analysis by means of relative thermal conductivity. Response time is said to be less than 30 sec. Construction permits use of a noncorrosive gas as a reference; optional connections are provided for a recorder. Dry cells supply current for portable operation; an external 6-volt, d-c source may be used. (P-32)



Photomicrographic Unit

Lovins Engineering Co., 8203 Cedar St., Silver Spring, Md. The Plenary microscope provides for cinemicrography with 16-mm or 35-mm camera, visual examination with eyepiece or ground glass, and photomicrography or photomacrography with up to 5 in. by 7 in. film or plate. Changeover from still to motion camera, with constant eyepiece observation, is instantaneous. An incubated stage volume has an operating temperature of 37° C regulated to ±0.05° F. Speci-

"MIGHTY MITE" SOLVES
CHEMICAL PUMP PROBLEMS

The Eco All-Chem Pump is the All-Teflon and stainless steel pump that handles 70 percent of corrosive chemical requirements in Lab., pilot plant and small volume pumping in production service.

Simplify selection; standardize on fewer types, models, sizes; minimize maintenance problems.

READ THE SPECS . . . SPECIFY AND TRY

- *Type Pump:* Positive displacement with two opposed axially oscillating impellers equivalent to duplex piston operation.
- *Volume:* ½ to 10 g.p.m. maximum at 1750 RPM (water).
- *Pressures:* to 70 psi.
- *Suction Lift:* Highest over widest temperature and viscosity range.
- *Corrosion Resistance:* Lowest corrosion rate due to internal flow pattern. Handles all chemicals that stainless steel No. 316 will handle.
- *Pump Operating Characteristics:* Linear delivery. No air entrainment. Non-foaming. Unequalled for safety in handling hazardous liquids such as nitric acid and hydrogen peroxide. Self-priming on non-volatile liquids.
- *Drive:* Applicable to direct motor drive at 1750 RPM, as well as to all other standard driving methods.

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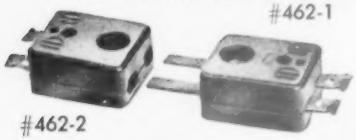
From Alden's Line of Ready-made Components for Unitized Plug-in Unit Construction:

No more blind connectors

#462-1

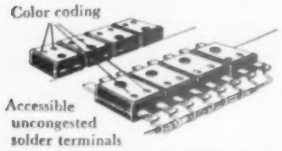


#462-2

ALDEN PATENTED

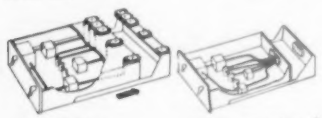
BACK CONNECTORS

Get accessible central check point for incoming and outgoing leads



EASY SERVICING AND RAPID CIRCUIT CHECKS

Solder terminals easily accessible and uncongested for multiple contact wiring. Color-coding on back connector, corresponding to lead color, identifies each lead for instantaneous check to main circuit or trunk line.

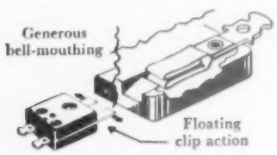


Permit direct efficient wiring

Avoid conventional rats nest wiring

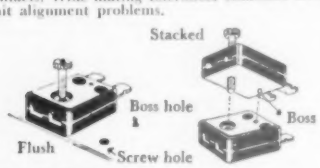
EFFICIENT CIRCUIT WIRING

Connectors can be mounted where desired — to allow for isolation of critical voltages or frequencies — to provide most direct wiring from component to connector — to eliminate rat-nest wiring of conventional methods.



EASY INSERTION AND REMOVAL

Made possible by large bell-mouth entries and ample float of rugged live-action beryllium copper contacts. Wide mating tolerances eliminate critical unit alignment problems.



EASY MOUNTING

Single screw for mounting flush or stacked. Molded locating boss positions and locks connector in place on unit when flush mounted — boss accurately lines up and positions connectors together in stack mounting.

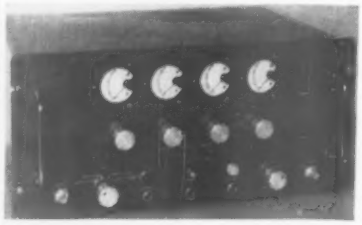
SEND FOR FREE SAMPLES

— also request free "Alden Handbook" 226 pages of techniques and components for Unitized Plug-in Unit Construction.

NA-ALO ALDEN PRODUCTS CO.

147 N. Main St., Brockton 64 Mass.

mens may be translucent or opaque and up to 50 lb. Illumination may be phase contrast, polarized light, dark field, incident light, oblique light, or bright field. (P-33)



Decade Counting Assembly

Digital Instrument Co., Inc., Box 1246, Coral Gables, Fla. The model 100 digital decade-counting assembly may be used as a simple divider, a counter with indicator, or as a preset counter with indicator. Only one of its three components is required for operation over the range 0–100,000 cps. All units are interchangeable. Power requirements are 6.3 volts at 1.2 amperes and 108 volts at 7 ma. Units can be cascaded indefinitely. Dual preset can be obtained with two preset switches on a single counter. (P-34)

Thermistor

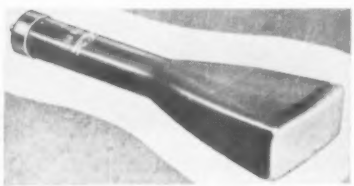
Victory Engineering Corp., Springfield Rd., Union, N. J. The type 71A2 thermistor has a temperature coefficient of $-7\%/°$ C at 0° C. Its resistance is 60 megohms at 0° C and 3 megohms at 50° C. The resistance element is sealed in glass. (P-35)

Digital Computing System

Remington Rand, Inc., 315 Fourth Ave., New York 10, N. Y. The ERA 1103 electronic digital computing system provides storage capacity up to 17,408 registers plus unlimited magnetic tape storage at an operating speed of 60 μsec per unit of addition. The system is applicable to automatic process control as well as scientific computation. Input-output systems to which the system is adaptable include magnetic tape, card readers, photoelectric tape readers, analog-digital converters, process-actuating mechanisms, and high-speed tabulators. The computer weighs 10 tons and has 4,500 electron tubes. (P-36)

Speed Recorders

Metron Instrument Co., 432 Lincoln St., Denver 9, Colo. The series 81M strip-chart recorders are General Electric type CF-5 instruments modified with tachometer indicators and heads to record speed; the recorders are inkless. Eighteen different speed ranges are available in virtually any units from 0–50 to 0–10,000. Charts are 4 in. wide, 65 ft long and have 50 or 60 minor divisions. Duty is continuous up to 30 days on a roll. (P-37)

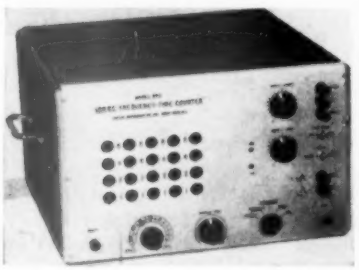


Cathode-Ray Tube

Waterman Products Co., Inc., 2445 Emerald St., Philadelphia, Pa. The model 3XP cathode-ray tube, designed for miniaturized oscilloscopes, is said to provide four times the light output and twice the vertical sensitivity of a comparable tube operating at similar anode potentials without sacrificing low interelectrode capacities. The tube is available with P1, P2, P7 and P11 phosphors. (P-38)

Ultracentrifuge

Specialized Instruments Corp., 668 O'Neill Ave., Belmont, Calif. The type SW39 swinging-bucket rotor can ultracentrifuge three separate 5.5-cm³ samples to a force of 178,435 times gravity at a maximum speed of 39,460 rpm. Sedimentation conditions approach those in a conventional sectoral analytical cell, providing minimum reorientation of boundaries upon deceleration to rest. A plastic stand is supplied to facilitate attachment and removal of buckets outside the operating chamber. (P-39)



Frequency-Time Counter

Potter Instrument Co., Inc., 115 Cutter Mill Rd., Great Neck, N. Y. The models 840 and 850 frequency-time counters directly count frequencies up to 1 Mc, or time the period of a cycle within 10 μsec. Elapsed time is measurable in increments variable from 10 μsec to 1 sec. Two unknown frequencies can be compared or a standard introduced. For use as a secondary standard, outputs are provided at 100, 10, and 1 kc, and 100, 10, and 1 cps. (P-40)

Ferro-Resonant Flip-Flop

Computer Research Corp., 3348 W. El Segundo Blvd., Hawthorne, Calif. The model 133 ferro-resonant flip-flop

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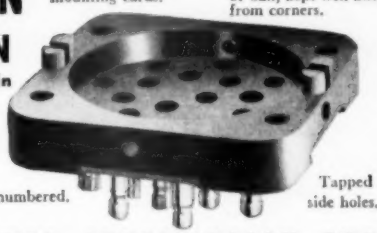

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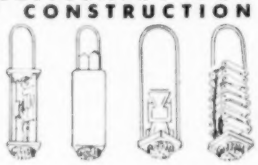

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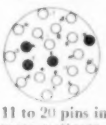
Choice of variable pin patterns guarantees against mismating. Color coding directs plug-in to its correct socket.



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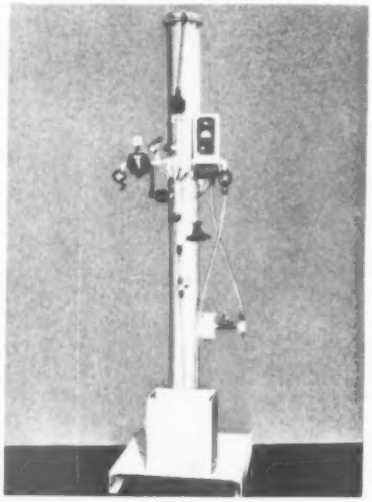


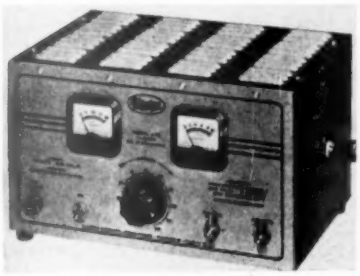
Water Demineralizer

Penfield Mfg. Co., Inc., 19 High School Ave., Meriden Conn. The model M-100 demineralizer, with a capacity of 4,500 grains, provides up to 100 gph of water equivalent to triple distilled; operating cost is claimed to be considerably less than that of distillation. Water intake is controlled by a flow meter on the influent. Installation space required is $2 \times 2 \times 7\frac{1}{2}$ ft. The exchange resin is regenerated by a system that is an integral part of the unit. (P-42)

Harmonic Generator

Computing Devices of Canada Ltd., Contract Department, Box 774, Ottawa, Ontario. The type C020 harmonic generator provides a 400-cps sine waveform and the 2nd, 3rd, 4th, 5th and 7th harmonics of this frequency. The phase of each harmonic voltage is

independently adjustable over a range of 360 degrees with respect to the fundamental. Instrument was designed for demonstration purposes with a cathode-ray oscilloscope. (P-43)



D-C Power Supply

Electro Products Laboratories, Inc., 4501 N. Ravenswood Ave., Chicago 40, Ill. The model C-12 power supply provides 0–16 volts, d-c, at 1–8 amperes continuous output and up to 12-ampere intermittent output. Filtered circuit reduces a-c hum or ripple to <3% at 8 amperes. (P-44)

Recording Camera

J. A. Maurer, Inc., Photographic Instrumentation Div., 37-01 31st St., Long Island City 1, N. Y. The mark 3 camera operates automatically up to 4 frames/sec. Film capacity is 21 ft of 35-mm film; two models are available, providing 200 1 × 1-in. frames and 300 ¾ × 1-in. frames. Operation is powered by a spring motor initiated by electrical pulses of 12 or 24 volts, d-c. Five shutter speeds from $\frac{1}{10}$ to $\frac{1}{200}$ are provided in addition to a time setting. (P-45)

Mass-Rate Flowmeter

Control Engineering Corp., 560 Providence Highway, Norwood 25, Mass. This meter is sensitive only to the rate of flow of mass of anything that flows or falls through a pipe. The meter is insensitive to volume, since it measures the torque necessary to give the flowing mass a Coriolis acceleration. It meas-

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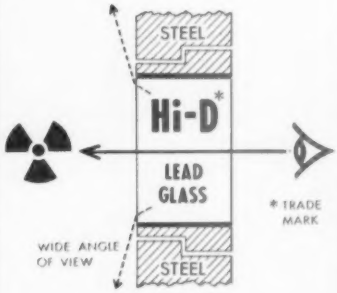

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ures multiphase or homogeneous fluids, aerated powders, or pieces falling by gravity. Meter output reverses when flow reverses, and average values of pulsating flows can be measured. The meter is custom built; however, the most vital industrial and military needs will be met first. (P-46)

Oscilloscope Probe

Linear Equipment Laboratories, Inc., Brightwater Place, Massapequa, N. Y. The model HF2A cathode-ray oscilloscope probe measures low-level signals in high-impedance circuits without signal attenuation by using stray capacities. Output impedance is 60 ohms; maximum undistorted output is 1.5 volts, rms. Signals up to 150 volts, rms, can be applied to the probe without overload. Input impedance on all ranges is 4.5 megohms with 1.5 $\mu\mu$f. (P-47)

X-Ray Spectrometer

North American Philips Co., Inc., Research and Control Instruments Div., 750 S. Fulton Ave., Mount Vernon, N. Y. The Norelco G-M counter X-ray spectrometer has an angular range of −10 to 90 degrees. The angle, read directly or from a strip chart, can be varied manually or by motor drive; counter position is readable to 0.01 degree. The X-ray generator provides fixed operation at 35 kv, 6 ma, and operates on 200–240 volts, 50 or 60 cycles. (P-48)

Analog-Digital Converter

Coleman Engineering Co., 6040 W. Jefferson Blvd., Los Angeles 16, Calif. The standard model Digitizer, an electromechanical analog-digital converter, operates at 18,000 rpm at the units decade; torque to start rotation of the units decade input shaft is 0.005 in.-oz. Models are offered in three, four and five decades; six decades and over can be furnished on special order. (P-49)

Ganged Potentiometer

G. M. Giannini Co., Inc., Pasadena, Calif. The Gangpot vernier-phasing ganged potentiometer is available with from two to six sections, each section available in 2,000–300,000 ohms. A six-section unit operates on 1.5 oz-in. shaft torque. Mechanical rotation is 360 degrees, continuous; electrical rotation may be 360 degrees or less. Sections may have linear or nonlinear output, one or two brushes, and taps as desired. Screwdriver vernier phasing is 22 ±0.2 degrees. (P-50)

INDUSTRY NOTES

▶**Technical Operations, Inc.,** 6 Schouler Court, Arlington 74, Mass., has appointed James E. LuValle, formerly research associate at Eastman Kodak Research Laboratories, as director of a project on fundamental photographic theory with emphasis on the chemistry and mechanism of development.

▶**Beckman Instruments, Inc.,** South Pasadena, Calif., has started construction on a 2-million dollar 200,000-sq. ft. factory and administrative plant in the La Habra-Fullerton area, California. First occupancy is expected in midsummer.

▶**Engineering Research Associates,** St. Paul, Minn., acquired last year as a subsidiary of Remington Rand, Inc., is now a division of that company. A new department, handling sales of electronic computer equipment, is headed by John E. Parker, former president of ERA.

▶**Isotope Developments Ltd.,** Finsbury Pavement House, 120 Moorgate, London, E. C. 2, has been awarded a contract by the Belgian Ministry of

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the Interior for the equipment of the Belgian civil defense with electronic instruments. The two types of portable equipment contracted for are for rescue operations and monitoring.

▶**Ohmart Corp.,** 2347 Ferguson Rd., Cincinnati 38, Ohio, has opened district sales offices in Chicago and Dallas. The district managers are Lester F. Boss, Chicago, and John W. Godbey, Dallas.

▶**Nucleonic Company of America,** 497 Union St., Brooklyn 31, N. Y., has announced that Alex Dzik is the company's new sales engineer.

▶**Nuclear Instrument & Chemical Corp.,** 229 W. Erie St., Chicago 10, Ill., has announced that future advertising and sales promotion will identify the company as "Nuclear-Chicago" to avoid confusion with firms having names similar to the corporate title.

▶**Wolfgang Huber,** director of chemical and biological research of Electronized Chemicals Corp. since 1945, has resigned as vice president of the corporation to enter practice as a management and research consultant. His business address will be 84 Livingston St., Brooklyn, N. Y.

LITERATURE AVAILABLE

Reinforced hose. Catalog 35 describes spiral-wire-reinforced flexible hose. *American Ventilating Hose Co., 100 Park Ave., N. Y.* (L-1)

Strip-chart recorders. Data sheet 81M gives information on recorders with ranges up to 100,000 rpm. *Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.* (L-2)

Persulfates. Bulletin 34 is a bibliography of properties and uses of persulfates. *Buffalo Electro-Chemical Co., Inc., Station B, Buffalo 7, N. Y.* (L-3)

Nucleonic equipment. British equipment is described in "Instruments & Accessories for Radioisotope Applications." *The Scientific Instrument Manufacturers Assoc., 20 Queen Anne St., London, W. 1, England.* (L-4)

Vault doors. Doors that offer fire protection are subject of folder SC-728. *Remington Rand Inc., 315 Fourth Ave., New York 10, N. Y.* (L-5)

Alarm system. Naval engineering report describes installation of automatic static alarm system. *The John Hewson Co., 106 Water St., New York 5, N. Y.* (L-6)

Thermistors. Data booklet discusses types and uses of thermistors. *Victory Engineering Corp., Springfield Rd., Union, N. J.* (L-7)

Assembly and wiring. "OK Methods" describes techniques for assembly of wire and cable to electrical connectors. *American Phenolic Corp., Dept. 13R, 1830 S. 54th Ave., Chicago 50, Ill.* (L-8)

Packaging Unit. Folder describes foam-rubber-cushioned metal container. *Greenwood Packaging Supply Co., 859–879 Summer Ave., Newark 4, N. J.* (L-9)

Galvanometer use. Bulletin discusses selection and use of galvanometers. *Trans-Sonics, Inc., Bedford Airport, Bedford, Mass.* (L-10)

Laboratory equipment. "Laboratory Specials" lists biological apparatus. *Aloe Scientific, 5655 Kingsbury Ave., St. Louis 12, Mo.* (L-11)

Anhydrous ammonia valves. Catalog 801 covers valves for use with ammonia and other gases noncorrosive to steel. *Henry Valve Co., 3215 North Ave., Melrose Park, Ill.* (L-12)

Liquid-level gages. Bulletin describes reflex-type gages. *Jerguson Gage & Valve Co., 80 Fellsway, Somerville 45, Mass.* (L-13)

Instrument mercury. Circular describes mercury and dispenser. *Bethlehem Apparatus Co., Inc., Front and Depot Sts., Hellertown, Pa.* (L-14)

Storage equipment. Catalog lists storage and maintenance equipment. *Precision Equipment Co., 3712 N. Milwaukee Ave., Chicago 41, Ill.* (L-15)

Level control. Brochure F-101 describes electronic liquid and solid level control. *Fielden Instrument Div., Robertshaw-Fulton Controls Co., 2920 N. 4th St., Philadelphia 33, Pa.* (L-16)

Liquid-handling equipment. Catalog 52 describes filters, mixers, cappers, fillers, pumps. *Ertel Engineering Corp., Clinton Ave., Kingston 8, N. Y.* (L-17)

Manometers and meters. Bulletin gives data on manometers, flow meters, orifice flanges and plates. *Trimount Instrument Co., 3119 W. Lake St., Chicago 12, Ill.* (L-18)

Relays. Circular 1702-A describes telephone-type industrial relays. *Automatic Electric Co., 1033 Van Buren St., Chicago 7, Ill.* (L-19)

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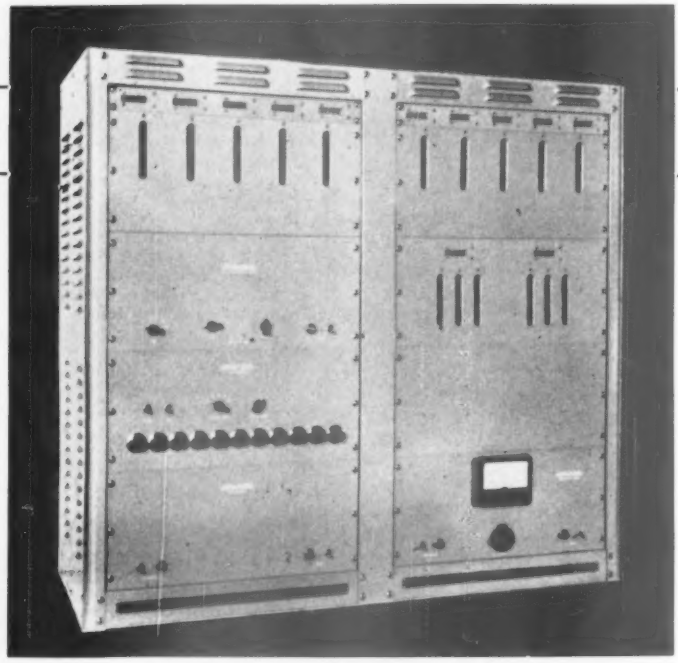

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ATOMIC'S 10-10 SCALERS ... to fit your needs without high "custom design" costs

There's no need to purchase high-cost "custom design" scalers to fulfill your particular scaling needs. Now, with Atomic's Ten-Ten Series you can have a regular production model scaler at modest cost, but with added features built into each of the seven models to modify the unit to your specifications.

These features are included in all models of the Ten-Ten Series:

- Plug-in scaling strips, interchangeable optional decade Scale-of-10 and binary Scale-of-16 assemblies (one or the other only).
- Plug-in input strip with preamplifier, true adjustable pulse height discriminator and gating circuits.
- External preamplifier input for attachment of special preamplifiers; supplies required plate and filament voltages.
- Front panel switches include: Count "ON-OFF" switch, reset switch and 60-cycle test switch.
- Built-in regulated high voltage supply with regulation of 0.01% per percent line variation and 0.5% regulation from zero to full load.
- High voltage does not overshoot during warmup and may be switched off and on without danger to counting tube.
- High voltage output on front panel makes output of low energy storage "safety" supply available independently.
- "Flutter Free" 5651 voltage reference tube.
- Electrically actuated register of proven design.
- Register drive output for attachment of external registers.
- Scope connection to input of discriminator.
- Test points on each strip for scope observation of outputs.
- Output for elapsed time clock controlled by count switch.

An extra feature that may be added to all models of the Series is the helical discriminator potentiometer.

Model 1050A.

● Contains all features common to the Ten-Ten series, plus the following special features:

Built-in linear amplifier, flat response from 10KC to 1.5 MC.

Resolving time: binary, 5 microseconds to 200KC; decade, less than 5 microseconds to 100KC.

Scale selector switch: 10-40-100-400-1000 or 16-64-256-1024-4096.

GM Probe input: 0.25 volt maximum sensitivity, 1 millivolt sensitivity through built-in linear amplifier.

Attenuator for L.A. gain control: ratios, 1:1, 1:2, 1:4, 1:8, 1:16, and 1:32.

Pulse height discriminator, precision calibrated: −50 to +100 volts.

Regulated high voltage supply, ten ranges: 500-3000 volts.

Electrically reset register, automatically resets with scaling stages.

Automatic — manual control switch.

Provision for: predetermined count, preset time, remote control, cascading and count rate meter.

● Model 1030A has the same features as Model 1050A, except that it has 0.25 volt input sensitivity only.

MODEL 1070A MULTISCALER

● Contains all features common to the Ten-Ten Series, all features of Model 1050A (listed above), plus the following special features:

Built-in elapsed time clock: automatic reset, 0-60 minutes, 1/100 minute divisions.

Built-in timing clock: presents from a few seconds to 20 minutes, accuracy ±1 second.

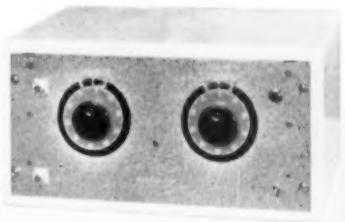
Electrically reset 4 digit register, with preset count switches, permits counting to 10X, 100X or 1000X scale selector setting. Automatically resets with scaling stages.

Automatic operation selector switch with choice of preset time, predetermined count or manual operation.

● Model 1060A has the same features as Model 1070A, except that it has 0.25 volt input sensitivity only.

Other more simplified models of the Ten-Ten Series (1010, 1020A, 1040A,) are available with scale of 100 or 256 and 0.25 volt input sensitivity.

Find out which model of the Ten-Ten Series is best suited to your needs. Write today for the descriptive bulletin.



PULSE HEIGHT ANALYZERS

Model 510 Single Channel Differential Pulse Height Analyzer — for pulse amplitude distribution studies with channel base line adjustable to 100 volts and window settable from 0 to 7 volts. Can be used with Model 204 Linear Amplifier and any of Atomic's Scalers to meet many nuclear laboratory needs.
NEW Model 520 Twenty Channel Differential Pulse Height Analyzer — takes accurate data on the amplitude distribution of electrical signals, having random amplitude and time distributions.

LINEAR AMPLIFIERS

Model 204B Linear Amplifier — for use with ionization chambers, scintillation and proportional counters. Rise time to 0.02 microseconds, gain to 15,000. Three-position band width switch. Dual attenuator, precision calibrated pulse amplitude discriminator. Low and high level output, self-contained power supply, provision for preamplifier.
Also Model 204C — similar to 204B with separate input time constant and rise time controls.

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